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Review article

Rural Sustainability for Security, Prosperity, Peace and Happiness

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Agriculture faced numerous calamities leading to import of food grain for the first time in 1921, that grew to alarming level in later years. Independent India accorded highest priority to agricultural development with establishment of projects of irrigation and power generation and implementation of programs for green, white and blue revolutions leading to self-sufficiency in food with surpluses for export. However, supporting 17 percent world's population just with share of 2.4 percent land and 4 percent water is hilarious task that bring pressure on resources. Exploitation of selective resources for increasing productivity has started showing distress signs in many areas. With least possibility of increasing share from available land and water for agriculture, the country has to manage sustainability to maintain food and nutritional security, prosperity, peace and happiness for population dependent on agricultural. Therefore, there is need for holistic cluster-based integrated development to improve rural infrastructure for education, health, road and transport, enable agricultural mechanization, processing and value addition and supply chain with training and skill development to benefit rural stakeholders. This paper attempts to suggest one such model for a cluster, which will improve further with water conservation and irrigation automation bringing in additional area under irrigation.

INTRODUCTION

Evidences prove that agriculture has been way of life in India since ages. The country had well settled civilized intellectual life in the 3rd century BCE. However, repeated invasions from 8th century onwards, leading to establishment of Mughal dynasty followed by British Rule till 1947, brought many changes in the life of people and the country. Independent India had huge task to manage food requirement for the population with poor infrastructure, production systems and dwindling economy. However, country's commitments to develop agriculture led to establishment of many irrigation and power projects and implementation of green, white and blue revolutions, resulting in self-sufficiency in food with surpluses. Our consistency with policies has made the country emerge as 5th largest economy with a largest vibrant democracy of people belonging to ethnically diverse groups, tribes and minorities. The country has come up with state-of-the-art infrastructure, physical prosperity, cultural dynamism and human resources of high order. However, it is still faced with many challenges and economic in equalities and therefore, it has to march with greater speed to next level with sustainable development to realize prosperity with peace and happiness.

It is, therefore, imperative to realign the policies and programs aiming for "Total Quality Improvement" in rural India to include infrastructure for education, health, road and transport with technology application in production, processing and value addition and other off farm activities. Rural India has untapped potential to unleash possibilities sustainable growth with continual enrichment of values, culture, tradition and ecology for peaceful coexistence with prosperity and happiness. The article attempts to suggest one such implementable cluster-based model would be replicable in other clusters with modifications.

ISSUES OF RURAL INDIA

India is blessed with productive land and varied agro-climatic conditions suited to grow many crops at one place and same crop elsewhere at different time. It has vast resources of scientific and technical manpower, technologies and hard working farmers. Macro level achievements in self-sufficiency with remarkable productivity and production of food, feed, milk, egg, meat, fruits and vegetables are laudable. However, issues like small and scattered land holdings, ineffective credit, insurance and procurement systems, non-delivery of subsidies to actual cultivators and failure in sure food and nutritional security to large population in spite of food sufficiency, need resolution to take the development to next level.

Most of our talks on agricultural development revolve around increase of productivity and production with missing concern for improvement in living conditions of rural society. The policy, program and strategy of development need to comprehensively and holistically address all issues to protect cultural landscapes caring soil, water, forest, grassland and other living creatures with natural resources. Policies should address the need of education, health care, food and nutritional of people and creation of environment for processing and value addition in rural India. Status on some of these issues are briefly discussed hereunder for better clarity and care to consider in preparing illustrative development model for sustainable growth to realize security, prosperity, peace and happiness.

FARMS RELATED ISSUES

1. The Population: Growth and Distribution

Population growth and large-scale migration of people is an indication of imbalanced regional and sectoral growth. Decadal percentage population growth in double digits (Table-1) from 60's onwards has resulted in increase of population from 361 million in 1951 to 1350million in 2017 registering 3.75 times increase during this period. The data further reveals the change in ratio of rural and urban population form 83:17 in 1951 to 67:33 in 2017. In absolute terms, urban population of 2011 surpassed the total population of India in 1951. By 2017, rural and urban population increased to three times and seven time the respective population levels of 1951 revealing very high rate of migration from rural to urban areas.

Despite the fact that urban areas do not offer any hospitable conditions to majority of migrant population, continued shifting reveal the serious issues in managing livelihood and survival in rural India. Such large-scale migration bring pressure on city infrastructure while desolating the rural areas of able workers. The situation is not sustainable for either of the places in long run. Therefore, creation of work opportunity in agriculture and agribusiness is the only solution to retain them happily in the rural area.

2. The Land: Agricultural land and distribution:

Total geographical area of the country is 328.73 million hectares. Out of this, about140 million hectares is under agriculture, cultivated by 138 million farm families, at about 140 percent cropping intensity (Table 2). The country has to support the 17 percent of world's population with only 2.4 percent of land share. It is evident that the number of marginal and small farmers grew from 49 million to 118 million between 1970 to 2011and at the same time land holders in medium and large categories reduced by 1 million and 3 million creating larger issues in mechanization and irrigation automation. In the given situation, collective farming through FPO/society/self-help groups can offer better solution enabling farmers to take advantage of automation for reducing the cost of cultivate and increasing the income.

3. Water: Availability and Irrigation facilities:

Total water on earth is estimated at 1386 million cubic km, of which96.5 percent is held by ocean, which is saline. Out of 2.5 percent fresh water, 70 percent is held as ice sheets and 30 percent in aquifers. India has only 4 percent share of

Table 1. Decadal change in population and distribution in rural and urban areas

Year	Population (Million)			Population (%)		Decadal increase (%)		
	Total	Rural	Urban	Rural	Urban	Total	Rural	Urban
1901	238.4	212.5	25.9	89.14	10.86			
1911	252.1	226.1	26.0	89.69	10.3	1.37	6.4	0.23
1921	251.3	223.2	28.1	88.82	11.18	-0.08	-1.28	8.24
1931	279.0	245.5	33.5	87.99	12.01	2.77	9.99	19.22
1941	318.7	274.5	44.2	86.13	13.87	3.97	11.81	31.94
1951	361.1	298.7	62.4	82.72	17.28	4.24	8.82	41.18
1961	439.2	360.3	78.9	82.04	17.96	7.81	20.62	26.44
1971	548.2	439.1	109.1	80.1	19.9	10.9	21.87	38.28
1981	683.3	523.9	159.4	76.67	23.33	13.51	19.31	46.1
1991	846.4	628.7	217.6	74.28	25.71	16.31	20	36.51
2001	1028.7	742.5	286.1	72.18	27.81	18.23	18.1	31.48
2011	1210.2	833.1	377.1	68.84	31.16	18.15	12.2	31.81
2017	1349.8	904.3	445.5	67	33	13.96	8.55	18.14

Table 2. Land holding size and land holding families (million)

Holding size	1970-71	1980-81	1990-91	2000-01	2010-11
Marginal (up to 1 ha)	36	50	63	75	93
Small (1-2 ha)	13	16	20	23	25
Medium (2-10 ha)	19	21	22	21	20
Large (Over 10 ha)	3	2	2	1	1
All sizes	71	89	107	120	138

world's water. The country gets 4000 BCM water as rain, against required 3000 BCM, but it is able to harvests only 8 percent of it. About 80 percent of available water is already deployed in agriculture, leaving about half of the area unirrigated. Huge share of irrigation and domestic water is drawn from poorly replenished ground reserves. Per capita annual water availability of 5155 cubic meter in 1951 has reduced to 1508 cubic meter drawing closer to water scarcity. Scrutiny of data area under irrigation (Table 3)indicate net sown area at around 140 million ha with increase in gross irrigated area and area sown more than once by 36.26 and 5.58 million ha in seven decades.

Table 3. Growth in area under irrigation

Irrigated area and area sown (Million ha)			
Year	Gross cropped area	Area sown more than once	Gross irrigated area
1990-91	185.74	42.74	63.20
2000-01	185.34	44.00	76.19
2009-10	189.19	50.02	85.09
2010-11	197.68	56.12	88.94
2011-12	195.80	54.82	91.79
2012-13	194.25	54.31	92.25
2013-14	200.95	59.52	95.77
2014-15	198.36	58.32	96.46

Considering the scarcity of water, our commitments of *"Water to every field"* and *"per drop more crop"* need to result in linking of rivers, equitable water sharing, charging of aquifers, optimizing cropping systems and enhancing water use efficiency. However, enhanced local collective efforts by society for water conservation and charging aquifer and management of ponds may result in boosting area under irrigation and supplement these initiatives.

4. Agricultural credit and Farmers debts

About 900 million people living more than 6.50 lakh villages in different are involved in agriculture and related activities with 138 million farm families cultivating140 million ha land. Land consolidation is poor in many states. More than 90 percent of families have less than 1 ha. holding, scattered at more than one location operate at suboptimal level and holders are hardly able to meet food and feed requirement. As such, the farmers remain under pressure of debts and face difficulty in arranging funds for to meet farm and other expenses. Almost all type land holders depend on all types of lending sources (Table 4) indicate that with majority of small and marginal farmers relying more on shopkeepers and money lenders paying higher rate of interest. They often end up selling their produce at cheaper rate.

Collective farming in groups may enable them to reach banks for availing crop loans and thus small and marginal farmers may get benefits of collective bargaining both in interest rate and also in selling their produce profitably.

5. Agricultural Mechanization

Farm mechanization and crop productivity has direct correlation. It saves time, labour, reduces crop losses and boosts farm income. However, it has poor feasibility for small and scattered land holdings due to cost of mechanization being high at individual levels. Overall mechanization in India is in the range of 40-45 percent, varying in degree between crops and operations. However, mechanization is essentially required to control the cost of operations, development and popularization of small and cheap machines suitable for small farmers is need of the hour. Consolidation of land, system of cooperative and collective farming and custom hiring can offer feasible solution.

6. Risk Mitigation

Prime Minister Fasal Bima Yogana (PMFBY) is operational in large parts of the country. Though, the scheme has gained popularity among producers of high value crops like cotton and sugarcane, it is yet to become popular among large number of farmers cultivating wheat and paddy over 70-80 percent land area. This situation is reported to be due to lack of unawareness coupled with procedural complications in filing the claims and payment by insurance companies. The issue of procedural formalities can be effectively handled while working in collectively farming system with facilitation of FPOs/ organizations.

OTHER ASSOCIATED ISSUES

1. Rural Education

Status of rural education gets reflected in the economic status of any country. Education plays an important role in

Table 4. Farmer debts with different sources in per cent (2013)

Holding Size	Co. Society	Bank	Money lender	Shopkeeper	Relative/ friend	Others
0-1 ha	10	27	41	4	14	4
1-2 ha	15	48	23	2	8	6
2-4 ha	16	50	24	1	6	4
4-10 ha	18	50	19	1	7	6
10+ ha	14	64	16	1	4	2

shaping the future of individuals. Study finds that over 100 million children, with overwhelming majority from rural India, do not attend school and also that boys get preference in education over girl child. Report admits that in education coupled with skill development has capacity to unlock huge potential of rural India. Another study reports the reason of crippled education as inadequate number of schools, poor transport, poor quality of educational institutions, inadequate Infrastructure etc., suggesting for increasing number of schools, use of technology in education, focus on conceptual learning etc. Interventions in rural education programs have not been able to address the situation adequately. Achievement of rural education is still assessed in percentage of literate and illiterate people instead of any higher expectations for qualitative improvement. Education and skilling rural India itself are huge task calling for lot of energy, time and money. Collective efforts from government, non-governmental Institutions and social leaders shall be required to make any break through to improve education in rural India.

Cooperative farming and social interactions, leading to building awareness about the benefits may contribute to great extent in spread of education and training for rural India.

2. Rural Health

Despite impressive economic growth for decades, the country holds poor rating in human development indexes due to prevalence of malnutrition, making the population susceptible to infections, increased mortality and poor quality of life. Seriousness of the problem vary from state to state with socio-economic conditions, ethnic groups, food habits, and health infrastructures etc. Malnutrition in the first six years of life renders lifelong adverse impact on growth, development and mortality. Rural India has higher risk of preventable death, illness and disability due to poverty, lack of nutrition, education, poor access to safe drinking water and sanitation coupled with lack of health care system. Since long cereals like wheat and paddy have been major staple food. Consumption of pulses, roots and tubers has fallen. Average diet remains largely deficient in vegetables, meat, fish, milk and milk products. Studies further indicate that rural population may acquire higher prevalence of diseases like diabetes, hypertension, coronary heart diseases. Change in the life style with food habits to include cereals rich in nutrients coupled with health education and management system may play greater role in preventing the situation.

Cooperative functioning with changed cropping system leading to production of nutrient rich cereals, vegetables together with ventures like fishery, dairy and poultry will make the diet rich for the family. Programs can also be arranged to educate people about healthy life style.

3. Rural Road and Transport

Despite the fact that India has largest and densest road networks, it still lacks all season motorable road for large percentage of people, particularly in rural India. Rural connectivity enables the movement of fertilizer and inputs to the villages and products of villages to cities resulting in growth of economic activities. Better connectivity helps in schooling, medical attention and attracts experts and investments to rural areas opening new business opportunities. Good roads connecting cities also reduce travel time and speed up the pace of development making village economy grow faster to join the mainstream. This is one of the strongest infrastructural need of rural India to bridge the city village divide and bring people together working in cooperation with each other. Good connectivity has potential to bring quality education, health and business in rural India. Cooperation among villagers and their togetherness can influence authorities to build these facilities in rural areas.

5. Convergence of Scheme Provisions and Confidence Building

Different schemes related to development of agriculture, forestry, soil and water conservation, irrigation, animal husbandry, dairy, poultry, fishery, sericulture, apiculture, animal feed, road, transport, food processing, education, skill development, rural health etc. concerning rural India are dealt by several ministries and departments of government of India and state. These schemes are prepared and implemented in rural areas in isolation without being able to address issues adequately. Some of the newer projects, launched with merging provisions different schemes, aiming at cluster development are yielding for better results.

There is need for basic change in the scheme provisions to realize comprehensive integrated inclusive and sustainable development of cluster to achieve millennium development goals at faster pace. Schemes emphasizing productivity, production and efficiency alone end up with exploitation of selective resources which distort the basics of holistic development. Suggested solutions involve convergence of scheme provisions to deal with cluster development to include techno-managerial input with multidisciplinary specializations and inclusion of AUs / ICAR and department in the process. This concept penetrates well in the society through FPO and society of farmers for developmental of a block level cluster consisting of 100 plus villages. Involvement of Institutions, departments and NGO together for support and hand holding will result in confidence building among farmers to participate in the process.

6. Economic Activities, Food and nutritional Security

Mechanization of farm operations, off farm activities like animal husbandry, milk production, poultry, fisheries etc. with development of processing, value addition and system of chain management of agricultural inputs together with training and skill development will enhance work opportunity and employability. Development of infrastructure related to road transport, facilitating education, health and technology transfer with hand holding will create confidence among rural community and bring independence. All this will accelerate economic activities generating employment and income resulting in increased purchasing power of people.

Increase in purchasing power will bring food and nutritional security among the masses. With change in suitable cropping pattern, increase in production, productivity and income, social security net gets automatically activated within the community locally ensuring that everyone gets one or the other opportunity to make enough earning. Support for the family not having any income starts coming from the community to ensure that no one goes without food in the village. This type of system and arrangement has been prevalent in the rural areas in India.

It is, therefore, imperative that rural India be provided with good infrastructure and system for education, health, road and transport. Cluster based feasible scheme coupled with convergence of government assistance and environment in the form of knowhow related to production, processing, value addition, marketing, supply chain system and training and skill development with hand holding to enhance income of the people. Encouragement to cooperative functioning in the villages for participatory inclusive growth will facilitate exploration of rural potential with sustainability and ecological balance.

METHODOLOGIES AND MODEL PLAN STRUCTURE

The methodology for evolution of model plan is based on the factual ground realities at present, what is required and how can it be done successfully to develop the rural community for their sustainability, prosperity, peace and happiness and get their best for nation building;

Present Scenario

Along with governmental efforts, many non-governmental organizations are working in rural areas to promote education, livelihood, skill development, plantation, soil and water conservation, wild life protection etc. All these efforts are being done in isolated manner, with most of them being limited to training and assistance to provide immediate relief. These efforts are not yielding desired results due to absence of required infrastructure and support system for complete assimilation to become self-sustainable. Hence a comprehensive well-coordinated developmental effort is needed to make the activities successful and self-sustainable in a cluster.

Some of the non-governmental organizations are working on the principles of comprehensive development based on scientific and technological advancements to help maintain synergy in food, energy, water and other resources. However, their activities and resources are limited and restricted to incoherent guidance, support and hand holding on limited scale.

Need

In order to make the program successful, completely coordinated activities shall have to be involved in the areas of (i) Intervention in quality education and health (ii) entrepreneurship development(iii) Training and skill development, (iv) development of processing, value addition and supply chain management system, (v) development of self-sustaining market linked agricultural ecosystem, (vi) encouraging cooperation in sports and cultural advancements, (v) involving non-resident villagers and government machinery with village people, research and educational institutions in evolving development plans for cluster and hand holding to ensure success.

Schemes and adequacy

It is found that schemes of government are available for development of almost all the aspects needed for comprehensive development of self-sustainable rural India. Adequate financial support is also provisioned under these schemes. They are being implemented but the process of development is slow and ineffective because individual schemes working in isolation of each other in uncoordinated manner without any convergence.

Way out and proposed system

There is need to implement schemes in coordinated manner with convergence based on the requirement of cluster. This will involve knowledge resource for design of program, support of government in convergence and assistance, organization of farmers, villagers and non-resident villagers for implementation, entrepreneurs for processing, value addition and marketing, organizational to support in training and skill development and hand holding.

It is proposed to involve farmers and villagers, government department, ICAR center/ agricultural university and NGO to take up development block consisting of 100-150 villages as cluster. It will have multi-projects, multi-organizations program structure working with understanding as team with Block level FPO/ Farmers as coordinating body.

Procedure

The process shall start moving in following manner;

i) A group of 5-10 energetic, enterprising youth with leadership qualities from the area shall come together who will be trained to convince others people about the initiative.

ii) A meeting of representatives shall be convened to form Farmers Interest Groups (FIGs), who will gather deeper knowledge about the cluster of 5-10 villages.

iii) Quality Circle Groups (QCG) shall be formed to discuss and prioritize the problems of cluster with possible solutions.

iv) Farmers shall be organized as Farmer Producer Organization (FPO) at Block level and also in cluster of 5-10 villages.

v) NGO will facilitate shaping these organizations, imparting knowledge and hand holding involving other resources, government organizations and knowledge partners.

vi) Cluster wise and Block level priorities shall be finalized by village people, non-resident villagers, government officers, university scientist and NGO.

vii) Program and projects shall be developed by a team of NGO, University/ICAR scientist which shall be submitted to local government for consideration and support.

viii) NGO will involve entrepreneurs and business persons interested in backward and forward linkages.

ix) Funds from government shall come to associated university/ ICAR center for spending as per government norms.

x) Additional funds shall accrue as equity, bank loan, etc. Interested companies will fund their own projects. Village persons can have independent ventures.

xi) Farmers and villagers will be owners of FPO and their company. All investment and earnings shall belong to them and professional working shall be encouraged.

Projection of opportunities attracts enterprises and business person to participate in the program bringing investments in rural area. Serious business startups in collective format will not have any problem due to involvement of local participants, government departments and public representatives. People will have proud feeling of contributing in the development of area together while generating income and employment.

Model Plan structure

The model development plan involving the concept of "Quality Circle", represented by farmers as owners have potential to prove corner stone for change. The process will yield better productivity combined with numerous opportunities for business, employment and income generation for farm families and rural youths. This will improve the economic status of farmers, bring happiness and enhance human development indexes among rural population. Such cooperative functioning shall enable implementation of any government schemes in all villages without any time lag with rural agency working as arms for government. Change in cropping pattern will lead to nutritional security. Organizational structure of farmers as Farmer producer organization, societies, self-help groups and as individual entrepreneurs with broad relations as given hereunder in Figure 1.

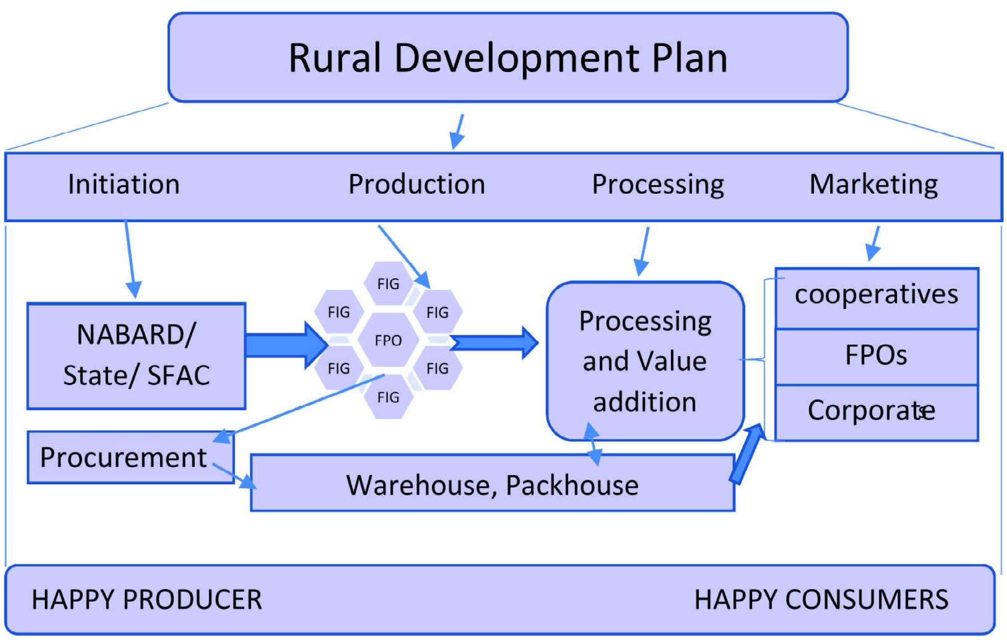

Figure 1. A model plan structure activity relation

Understanding Material Movement Matrix

Traditionally surplus production of farms is bought by Government agency/ traders. Small farmers have very poor reach to government purchases. Traders do not offer remunerative rates. Processing of material take place in cities and processed material is sold to city consumers accruing profits to traders and processors. Labour comes from the villages to urban areas for employment and education of children. However, in the proposed system, the produce can be purchased by the farmer's organization in the villages itself processed within the cluster providing employment. This material can move for sale both rural as well as urban areas. Material movement matrix, containing indicative list of material, from rural to urban area and vice versa is depicted in Table 5 hereunder;

Table 5. Movement matrix of inputs and outputs of agriculture and other resources

Village to villages	Village to cities	City to villages
Food items, organic manure, pesticides, seeds, labour, Farm equipment etc.	Food items, Fruits and vegetables, oils, meat, poultry product, milk and milk products, Jaggery, seeds, saplings, building materials, labour etc.	Factory made consumables/ items, input material for processing, agricultural machinery etc.
		Health facilities, medicines, education and training, knowledge & skill, research products, investments etc.

The changed scenario, labour will remain in the rural cluster itself and local FPO/organization will have all profits that is presently not coming to villages. City dwellers will get quality material at cheaper rate, may be through direct home delivery or through local cooperatives in the city. This will result in a development model with seamless movement of food and other goods and services from village to city and education, technology and health services from city to village in the manner given in Figure 2 below;

Rural Waste Management

Agricultural residue management is becoming matter of concern to check pollution in cities. A system notionally depicted system (Figure 3) utilizes all bio degradable and animal waste to convert as manure, bio-gas and generate electricity fulfilling the objectives of clean and green India mission providing cheap fuel, manure and energy in rural areas.

ILLUSTRATIVE INTEGRATED DEVELOPMENT MODEL

Ghorawal Block of Sonbhadra district has been selected for development of illustrative model. Son bhadra is the second largest district of UP with major portion of land under forest which is rich in medicinal plants and biodiversity. Productivity of some of the crops are low owing to poor and degraded soil, poor water availability and low technology inputs, and cultural practices. The population of this hilly forested tribal region is enmeshed with plant eco-system

Figure 2. Supply system for material, labour, education and services

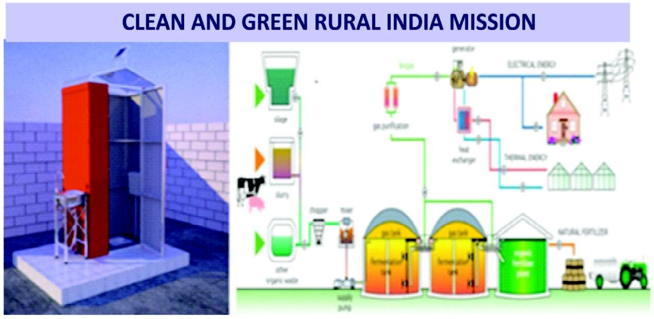

Figure 3. Providing clean energy to rural areas

dependent mainly on agriculture for income and survival. The district is bounded by four states e.g. Madhya Pradesh, Chattisgarh, Bihar and Jharkhand. It has three Tehsil and 8 Blocks for administrative convenience, out which Ghorawal offers challenges and opportunities both to develop as sustainable organic production zone.

Population and Topography

As per 2011 census, the population of whole district was18,62,559 with rural and urban settlements in the ratio of 83:17. Ratio of male and female population was52:48at d population density of 270 persons/ sq. km. Tehsil wise information is as under;

Sl no	Tehsil	No of villages	Area (km²)	Population	Literacy (%)
1	Dudhi	300	2690	670183	67
2	Ghorawal	346	859	290546	59
3	Robertsganj	796	3356	901830	84

Based on topography, soil type and micro-climate, the district offers four distinct characters suitable for production of almost all the crops like cereals, pulsed, oilseeds, fodder, fiber and vegetables beside being suited for fruit production, social forestry, harnessing of medicinal and aromatic potential and developing grazing units for cow, goat and sheep. Normal rainfall is about 945 mm from SW monsoon starting in 3rd week of June for 38-40 days. Intensity of winter and summer rains are low with short duration requiring supplemental irrigation.

The Project Area

Highlights for selecting Ghorawal as project area are as under;

- The area falls under backward and aspirational district.
- The district gets support from Backward Regions Grant Fund (BRGF).
- The area with densely populated industry has better marketing feasibility.
- The Block has higher population density of 333 person/ sq. km.
- Local enthusiastic youth, public representatives are ready to work for the project.
- Present condition of population health, education and other indices are poor.
- Nutritional status among children, ladies and general public is poor.

The Development Program

The program shall have following types of interventions in the development process;

- Productivity enhancement: "Low Input-High output Strategy", Precision farming, Nutritional and organic farming.
- Income enhancement: Off farm activities like Animal husbandry, Back-yard poultry, Fisheries, Goat and sheep rearing, dairy, Mushroom cultivation etc.
- Employment and income generation: Entrepreneurship in processing and value addition and marketing activities.
- Coordinated Catchment development: Interventions in education, health, road& transport, social forestry, Grazing land, soil and water conservation, medicinal and aromatic plant, women empowerment, food and nutrition programs and care for children development, aged and ladies etc.

Project interventions will enhance productivity, reduce cost of cultivation, create off farm activities and income and develop processing and value addition activities in the area. It will also improve education and health services, soil and water conservation, application of micro-irrigation technologies. Women empowerment with their participation in development and

Land and utilization

Basic details on land availability under Gorawal Block and utilization is given in Table 6.

It is evident that out of the total available area of 83997 hectares in the block, 31.72 percent is covered under forest. The forest is rich in medicinal and aromatic plant and biodiversity. Considerable land under forest area is covered by short height bushes. Tribal population can be engaged partially to care forest and collection of medicinal plants. Area not densely covered by trees can be enriched and developed as grazing land for animals. Cultivable barren land is small area that can also be developed as grazing land. Put together other land which is of non-agricultural use accounting for about 12.10 percent can be converted under horticultural crops. Area under agriculture accounts for 55.10 percent of the total area of the block.

Out of net area of 46239 hectares available for agricultural operations, area of 27773 hectares is sown for

Table 6. Basic land details of Ghorawal block

Sl No	Land utilzation	Area (ha)
1	Total area	83997
2	Forest area	26645
3	Cultivable barren land	447
	Barren land	2934
	Non agriculture use	1045
	Grazing land	52
	Horticulture	895
	Other use than agriculture	4770
	Total	**10143**
4	Net cultivable area	46239
	Area that is cultivated more than once	27773
	Total sown area	**74012**
5	Rabi	35360
	Kharif	30369
	Jaid	13
	Total sown	**65742**
6	Net irrigated area	28334
7	Gross irrigated area	33746

Source: Ghorawal Block office

more than once accounting for gross sown area of 74012 hectares. It is observed that irrigation is not available for all the cultivable land. The net irrigated area is to the extent of 28334 hectares only. These irrigation sources cater the need of additional area of about 5412 hectares in other season, thus accounting for total gross irrigated area of 33746 hectares. All available cultivable land is not completely sown in any of the season. Sowing depend on availability of water in reservoir that is likely to be available for irrigation. However, it is generally expected gross sown area of about 65730 hectares could be cultivated in both the seasons put together. An area of about 8000-9000 is covered in vegetable production together in both seasons. It is therefore, revealed that more area can be brought under cultivation with sufficiency of water from canal, local arrangement of tube well or storage of water in ponds/ charging aquifer coupled with application of micro-irrigation applications. It is estimated that about 15 percent increase in the gross cultivated area can be achieved with irrigation arrangements. Details about the cultivation of major crops in the block crops, other that vegetable, is discussed in following para.

Major Crops

Cropping system is dominated by Rice-Wheat cultivation with other nutri-cereals, pulses and oil seeds and huge production of quality vegetables. Existing production with productivity with expected improvement in near future with same area as practiced is as given in Table 7;

Table 7. Area, production with and without project

Sl no	Crop	Area (ha)	Yield (MT/Ha)	Production (MT)	Expected yield (MT/ ha)	Expected Production (MT)
		Rabi season				
1	Wheat	15029	2.43	36505	3.00	45087
2	Barley	894	1.90	1699	2.00	1788
3	Maize (Rabi)	7	3.50	25	6.00	42
4	Gram	1210	1.51	1821	1.90	2299
5	Peas	743	1.20	892	1.50	1115
6	Lentil	1610	1.02	1639	1.20	1932
7	Mustard/ Rye	710	0.73	518	1.50	1065
8	Toria	251	0.94	235	1.50	377
9	Lin seed	770	0.55	424	1.00	770
	Subtotal	21224		43756		54474
		Kharif season				
10	Paddy	9393	2.90	27240	3.00	28179
11	Maize (Kharif)	1253	1.19	1491	6.00	7518
12	Jowar	470	1.63	764	2.00	940
13	Other grains	860	0.76	654	1.10	946
15	Urid	800	0.67	532	1.00	800
16	Moong	20	0.50	10	1.00	20
17	Sesamum	430	0.39	166	0.45	194
18	Ground nut	70	1.21	85	1.40	98
14	Pegion pea	590	1.00	590	1.00	590
	Subtotal	35110		31530		39285
	Total	**56334**		**75286**		**93758.5**

Source: Ghorawal block office for area, yield and production

Likely increase in production is expected to be around 25-30 percent due to interventions of quality input and practices. This production will be sufficient for the food and nutritional security for the expected population of the block by year, 2021.Further additional growth of production can be achieved by bringing in additional 15 percent area under cultivation with expansion of irrigation. This will give the production of block to cross the more than 10 lakh MT (metric ton) as against present production of 75286 MT accounting for direct increase of income of the farmers about 45 percent.

Another area of improvement would to increase income and improve productivity by reducing input cost and losses with introduction of mechanization of agriculture. Further, the additional area becoming surplus from production of main crop can be diverted to the production of high value crops like oil seeds, pulses and vegetables that will give increased income to farmers. Area can also be diverted to the production of fodder for the animals proposed to be reared, fruit crops that would be needed for processing, Sweet corn, baby corn and increase of area under maize crops, seed production, vegetables etc. Program activities that are proposed to be taken up in the area will double the income of farmers with ease with these measures alone from their farms leaving the income that will accrue with incentive for value addition and off farm activities.

Program Activities

A. Production, productivity enhancement, processing and supply

An illustrative list of programs, project activities to be undertaken are given in table 8.

Table 8. Program, project activities and responsible entities*

Sl no	Program	Project activity
1	Cereals, Pulses, oilseed	Production, collection, Processing and packing
2	Sweet corn, baby corn, HQPM	
3	Fodder and Feed Production	
4	Mushroom Cultivation	
5	Animal rearing (Cow, Goat etc.)	
6	Milk production	
7	Fruit Production	
8	Poultry and Fisheries	
9	Seed production	
10	Moringa cultivation	
11	Medicinal and aromatic plants	

Projects and products

Following project can be taken up (Table 9) centrally or in decentralized mode with different FPOs/ individual entrepreneurs under control of guidelines for quality and cost management.

Table 9. Projects and products

Sl no	Project	Products
1	Flour milling	Flour of wheat, maize, jowar, Bajra, dalia, maida, besan,
2	Dal milling	Whole and split dal of gram, urid, moong, lentil etc.
3	Oil extraction	Oils of mustard, linseed, sesame etc.
4	Rice milling	Different rice products
5	Seed processing	Seeds of cereals, oilseeds, pulses, maize etc.
6	Canning	Canned products from baby corn, mushroom, vegetables
7	Pickles	Mango, karonda, amla, Carrot, Chilies, Jackfruits etc.
8	Bakery	Bakery items from wheat maize and millets
9	Fodder, feed, concentrate	Fodder, feed and concentrate for animals, Poultry, Fishery
10	Animal husbandry	Production, demonstration and sale
11	Dairy	Production of ghee, butter, curd, sweet milk etc.
12	Fruit processing unit	Packing of fruits and vegetables, juices and sauces etc.
13	Production of fruits	Production of fruits guava, mango, banana, papaya, ber etc.
14	Production of flowers	Production of different flowers
15	Nursery production/ TSL	Nursery for fruit, forest tree, vegetables, flowers etc.
18	Poultry units	Layer birds, hatchery unit, egg production
19	Fish production units	Fisheries production
20	Custom hiring centers	Centers for hiring machinery, tractors and harvesters etc.
21	Biogas and energy unit	Setting up of bio gas and energy units
22	Compost/ vermi compost	Preparation of manures from bio waste.
23	Bio pesticides	Preparation of bio pesticides.
24	Rural godowns	Construction of rural go downs.
25	Fodder production	Production of green and dry fodders.

Product and by-products matrix

Preparation of a consumable product brings rejection which shall form raw material for another product till conversion of whole produce to follows “energy to Energy” cycle. Chemicals shall not be used to ensure that the process attain organic certification standards with due gestation as per scheme. Product and by-product matrix are given in Table 10.

B. Production and Crop Husbandry Projects

Schemes of government support production of

Table 10. Product and by-products

Product	Eatables	Processing Reject	Harvesting, Threshing reject
Wheat / Maize	Flour/Maida/Suji/ Dalia	Husk, Bran, brokens	Straw, grain etc.
Paddy	Rice, Brokens	Husk, Bran, Broken	
Maize	Baby/ sweet corn,	Rejected cobs, Husk, grain	Stem, straw, leaves, grains etc.
Millet	Flour, Biscuit, Bread	Small grain, Husk	
Pulses	Whole, Dal, Besan	Husk, coat, broken, etc.	Stem, straw, leaf etc.
Oilseed	Oil	Oil cake, Leaves	Stem, straw, leaves etc.
Milk	Milk and milk products	Waste	
Poultry & Fish	chicken, Egg, Broilers	Egg shell etc.	Poultry manure.
Seed	Seeds	Reject grain, husk	Straw, grain etc.
Banana	Banana	Banana skin	Banana stem
Goat rearing	Meat and milk	Wool, skin	
Milk animals	Milk	Animal dung, Urine	
Moringa	Vegetable and leaf	wood	
	Human consumption	Animal feed, gas, fuel, electricity manure, etc.	Fuel, mushroom production

nutritionally fortified crops, certified seeds of vegetable, medicinal and aromatic cultivations, production of fodder, development of grass land for grazing etc. which can be aligned to benefit the farmers in the area.

C. Health Management

People can be encouraged for coverage under Ayusman Yojana. General health checkup can be periodically organized by FPO in consultation with health department. Also, ambulance services can be created and organization can work as an arm of government in the area.

D. Cattle Health Management

On the lines of health management system for human beings, arrangement can be put in place for medical checkup and insurance of animals in the area.

E. Care of Elderly People

Elderly people can be cared by a group of people in the village. Schemes available in this regard shall be aligned to serve elderly people and extend care.

F. Children Care

Arrangement of A-2 milk for children till 6 years of age, timely immunization and facilities for sports, games and intellect development and inter-village competition can be encouraged aligning the provisions of government schemes in this regard.

F. Motherhood Care

A dedicated group of ladies can be formed to take care of nutritional diet, health etc. for pregnant and lactating mothers. Sanitary pad, immunization etc. and training can be organized in assistance with government setup. Efforts will align with the government system in the villages off load government from this burden.

G. Food and nutritional security of Landless people

With the project in place landless working hands will have enough jobs and earnings locally to buy food. Support provisions are available in government scheme also and FPO can ensure that no one goes without food. Such initiatives shall also reduce burden of government also.

H. Resident non-resident villagers Gathering

It is most important event to bring together all villagers living in the city to village once or twice a year together which will work as important linkage between the two for success of program and sharing of responsibilities. Problems like education of children, improvement in education and health system and sale of village produce can get solution from such meetings. This event can be a platform to promote traditional cultural and social activities also.

BENEFITS

The planned model will offer following benefits for happy, healthy, prosperous and peaceful living;

- Income of farmers shall get doubled and will increase further with off farm activities and incentives from processing and value addition activities.
- Local processing and value addition will create jobs.
- Small and medium farmers will get reach to institutional credit support.
- Farmers organization will hold the whole chain and rural sector contribution in economy will improve.
- Economic activities in the village will increase purchasing power of villagers.
- Soil health and water availability and ecology will improve.
- Readymade market for village production. Surplus material can be purchased by FPO for government and stored in rural go-downs for PDS distribution.

- Processed and value-added locally branded material will get ready market.
- Cleanliness and disposal of biodegradable will check pollution.
- Support as per current schemes with convergence are adequate.
- For surveys, programs and schemes, FPOs can work as arm of Government.
- Health of children, mothers and rural education and health system will improve.
- Digitized system starting from soil testing till marketing aligned to central digital system will provide complete information on rural India.
- Nature will get relief to adjust for ecological balance and sustenance.
- Human beings, livestock, plants will get way to live in consonance with nature.

CONCLUSION

Rural development plan clubbed with waste utilization system will give birth to a clean, healthy, educated, prosperous, and competent villages. Rural cluster based comprehensive developmental will enhance production, open up numerous business as well as employment and services and consumable. This will associate business persons, manufacturers of plant and machines, storage facilities, education and health services, training and skill development that will bring investments in rural areas.

The plan will discourage migration from rural to urban areas, reduce burden of commutation giving rise to clean and green environment. Preparation of bio gas and electricity from waste will provide gas, manure and electricity in environment friendly manner reducing health hazard in the locality and nearby city. Seamless movement of consumables from rural to urban areas and education, technology and health services from urban to rural area will open new vista of city-village bondage of mutual respect and cooperation on level platform.

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Review Article

Horticultural Prospects for Rural India

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Key words
Horticulture technology, Rural agriculture, Livelihood security, Protected cultivation

Resource crunch of land, water, and finance in rural India is well known. This has now become very visible resulting in loosing interest in agriculture especially by rural youths. Horticulture is becoming popular due to comparatively better returns and technologies. Improved technologies including low cost technologies for adopting horticulture by rural youths along with traditional agriculture practices have bee n emphasized in this article supported by details of technologies/innovations, success stories and empirical evidences. Prospects of horticulture in rural areas are brighter as people are becoming nutrition conscious resulting in increased consumption of horticulture produce besides better returns from horticulture crops.

INTRODUCTION

Horticulture deals with food (fruits, vegetables, spices, condiments, honey mushroom, tea, coffee, cocoa and others), non-food (fiber, bamboo), medicinal and aesthetic crops production sand their post - harvest management including value addition. Horticulture crops particularly fruits and vegetables are rich in human nutrition, have very short (month) to very long duration (years) crops yielding not only high biomass but high economic return too in several forms related to food, nutrition, medicine beverages and others.

Horticulture is significant to our day- to- day life. One starts his/her day very first in the morning from horticultural produce by taking a sip of tea, coffee, chocolate, cocoa, and others. Brushing teethes with toothpaste made of neem and other plants, herbal soaps, shampoos, shikakai, aonla, coconut oil, lotions, deodorants, oils, perfumery to be ready for the day. If he/she goes for pooja, it is dhoop, agarbatti and pooja samagri made from the horticultural produce. In breakfast, one enjoys juices, jams, jellies, fruits, wafers, nuts, berries etc. Vegetables, salads, herbs, condiments and spices, make his/her lunch and dinner very nutritious and palatable. Ice-cream, betel, betel nut, fennel etc. are enjoyed as essential items after meal. Above listed are horticultural produce.

Food, nutrition and livelihood security have been a cause of concern across the globe and can be achieved by switching on adequately to horticultural crops. Being heavily populated with enormous bulge in numbers India is much more concerned with these. By default (not because of policy- no concrete resource rich planning or target for horticultural crops) Indian horticulture production has historically crossed 300 million tonnes marks dominated by vegetables, more than half of this, from mere over 250 million hectare. Hence horticulture is going to play a significant role in providing food, nutrition and livelihood security not only to the farmers but to the nation.

Rural India is chronically infested with poverty and poor economic condition of farmers. Agriculture, main occupation in rural India both for landholders and sizeable population of no farm land holders. Despite so many promotional programmes and incentives, in the past and present, by state and central Governments, agriculture/ horticulture is no more a preferred profession at least with the youths. Youths in rural areas of the country are no more interested to be agriculturists/horticulturists. This is obviously because of our faulty policies. Fragmentation of land holdings and their continuously decreasing size is making farming of grain, oilseeds, pulses etc uneconomical. Large acreage of farms/fields are still rainfed which may and may not yield depending on normal rains. In areas with irrigation facilities food crops like wheat, paddy, sugarcane and other non-horticultural commercial crops are grown barring few belts in some states, where horticulture crops are dominating.

It has been observed, no data on the subject, that horticulture farmers are by and large better off than cereal farmers irrespective of land holding. Small land holdings are suitable for certain horticulture crops (vegetables, flowers, and herbs) to provide enough employment and economic return to a family on regular intervals throughout the year in rural India. The research and development are concentrated on cereal, oil seeds and pulses with inadequate emphasis on horticulture mainly in terms of resource. To improve economic condition of rural people or doubling farmer's income by 2022 due emphasis rather more emphasis need to be given on rural horticulture and animal husbandry through government policies and allocation of more resources. In this context here we are deliberating prospects of horticulture in rural India under heads listed below.

Horticulture nursery in soilless medium

The horticulture crops nurseries are now gradually being multiplied in substrates other than soil eliminating possibilities of spread of soil borne pathogens from infested soils, making transport of planting materials easy and its use at ease and convenience as the short shelf factor of uprooted seedlings has been taken care off. Micro propagated plants and grafts do better in substrates other than soil preferably under semi or fully controlled climate (Singh 2015, 2018c,d; Singh et al. 2014, 2015). Biodegradable nursery bags/plugs have also been innovated and being perfected and popularised. Farmers should demand nurseries of horticulture crops in soilless medium facilitating adoption of soilless nursery production by horticulture nurseries. Accreditations of horticulture nurseries should be made mandatory to have health true to type planting material which is must for better crop yield and return. Farmers in the business of horticulture nurseries can haveFPOs/co-operatives/federation for supply or sale of plants/nursery. Modern nurseries fetch better profit.

Vegetable and flower seed production

Vegetable seed production is paying proposition. Depending upon the geographical and climatic conditions farmers in rural areas in collaboration with horticulture seed companies can have seed production of improved varieties and hybrids. Okra/bhindi, garden pea, number of flowers and medicinal plants seed production is easy for which there is a vast market (Singh 2015, 2018b,c; Singh and Kalia 2005) . This can give more income per unit area and employment to rural people both landholders and landless. Hybrid seed production is much more paying which can be taken up by undergoing training at KVKs, Agri. Universities and private seed companies.

Vegetable Grafts: As in case of fruit crops grafted seedlings in vegetable crops , where resistant root stock of same or other vegetables is used, are in demand to overcome stress (bio & abiotic) in production and reduction in use of chemical pesticides. Needless to emphasize that vegetable grafts multiplication is paying profession being practiced by certain private companies (Fig. 1).

Fig. 1. Grafted brinjal plants (Courtsey: VNR, Raipur)

ADOPTION OF INNOVATIVE HORTICULTURE PRODUCTION SYSTEMS

Horticultural crops by and large are grown under irrigated condition. Water for irrigation is becoming an important input which in coming years would be a scarce resource but essential. It is, therefore, essential to increase water use efficiency. There is an important slogan and national objective in agriculture "More crop per drop". To achieve this luckily Government is aware of it and rightly popularising micro irrigation (drip and sprinkler) and discouraging flood and furrow irrigation by extending financial support. To minimize quantity of chemical fertilizers by checking leaching etc their application with irrigation water popularly known as fertigation is becoming popular. With Government supports drip/sprinkler irrigation and fertigation be adopted in production of horticulture crops.

There are several new and innovative systems coming up in horticulture crops production and post- production besides using high yielding hybrids/varieties (Singh and Peter 2014; Singh et al 2014, 2015). Climate change has disturbed agriculture production systems, Horticulture is no exception. Among the horticulture crops certain crops are amenable to protected cultivation. The protected cultivation systems are: plastic mulch, plastic/nonwoven fabric tunnel, walk in tunnel, high roof tunnels with ventilation, insect proof net houses, shade net houses, naturally ventilated Polyhouse, climate controlled greenhouses, rain shelter, plastic wall or straw wall and bamboo structures/ staking technology. These systems are becoming popular in different parts of the country depending upon the climatic conditions and the type of crops grown. The most important, practical and affordable production system in major parts of the country are plastic mulch, low tunnels, walk in tunnels which are affordable and remunerative. In brief they are explained below.

Plastic Mulch

In this technique crops grow through the holes in the thin plastic sheets. This is used in conjunction of drip irrigation is used mainly to conserve water and suppress weeds. Certain mulches act as barrier to keep methyl bromide, a powerful fumigant and ozone depleting agent, in the soil. Disposal of plastic mulch is a concern; however technologies exist to recycle mulch into reusable resins. Bio-degradable plastic suitable for mulching would also be available in near future.

Benefits

1. *Early planting and faster growth:* Dark and clear mulches intercept direct sunlight thereby reducing soil temperature, hence facilitating early faster growth.
2. *Soil moisture retention:* Plastic mulches reduce the water

loss due to evaporation which means there is less water requirement for irrigation and even distribution of moisture reducing plant stress.

3. *Weed management:* Plastic mulch prevents weed growth by preventing the sunlight from reaching the soil and by blocking the pathway for the weeds to grow.
4. *Optimizing fertilizer usage:* Drip irrigation with plastic mulch reduce the leaching of fertilizers below root zone thereby ensuring that the nitrogen and other nutrients are applied only to the root zone as needed. This greatly reduces the fertilizer requirement as compared to broadcast fertilization with flood and furrow irrigation.
5. *Crop quality:* Plastic mulches reduce contact of fruits and vegetables with soil thereby reducing fruit rot and keeping the produce clean.
6. *Better Soil aeration:* Plastic mulch reduces crusting effect of rain and sunlight and quantity of weed resulting in better soil aeration and aiding microbial activity.
7. *Root damage reduction*: Reduction in weed eliminates the need of cultivation ensuring lesser root damages and improving overall growth of plant.

Disadvantages

1. *Cost:* plastic mulch comes at a much higher cost as compared to bare soil planting. The cost components include equipment, plastic film, trans-planters for plastic beds and additional labour for installation and removal of films.
2. *Environmental concern:* Conventional plastic, used as mulch film tend to accumulate in soil as the disposal of these are economically and technically difficult. Biodegradable plastics are a good substitute as they get eventually degraded by microbial community. Use of used plastic has become possible for road carpeting.

Suitable Crops

Most of the horticulture crops are amenable for plastic mulch in different ways.

Low Tunnels

Low tunnels which alternatively also called as "Plastic Tunnel" as cladding material is largely plastic/polyethylene now nonwoven fabrics, are small greenhouse-like structures, covering the plants along the row with or without provision of ventilation manually (Fig. 2). These tunnels are erected with wire hoops and covered with clear plastic/ nonwoven fabric. The tunnels promote early growth by warming the air surrounding the plants, using heat from the sun. The tunnels also protect plants from frost that can destroy or damage them.

Fig. 2. Overview of Low tunnels- non woven fabrics

Benefits

1) Creates suitable micro-climate for growth and development
2) Enables earlier seeding hence larger yields
3) Protecting the plants against insects and birds
4) Protects from hailstorms, frost, and heavy gusts of wind
5) More cushioning effect to the soil surface
6) Better gas exchange capacity thus less suffocation to root
7) Reduction in the need for chemical treatment of plants
8) Off-season or early production
9) Better air/water and gas permeability.
10) Can provide local greenhouse effect

Suitable Crops

Various crops such as squash, melons, tomatoes, green pepper, hot peppers, cucumber, watermelon, pumpkin lettuce, carrots, radish, cauliflower, potatoes, spinach/palak, leeks, herbs strawberries and flowers and others are suitable crops in poly houses (Singh et al. 2015).Use of low tunnels isan effective method of frost protection, both inside a high or walk-in tunnel and in field production. Usefulness of low tunnels varies with crop and production system.

Walk-in-Tunnels

Walk-in tunnels are low-cost crop season-extension crop protective technology used for producing a diversity of horticulture crops generally vegetables, fruits (strawberry), herbs and flowers. Specifically, walk-in tunnels are passively vented, solar greenhouses covered with 1-2 layers of greenhouse plastic with or without mechanically ventilation (Fig. 3).Walk in tunnels help farmers to extend growing off season both early and late crops, nursery multiplication for increase in productivity and profitability. They help in protection of crops from low temperature, high wind, storm and rainfall and ensure risk free production. High tunnels are made in many different shapes, sizes and structures. They can be as small as 1000sq ft and as big as an acre. Plastic cover can be removed during hot summers or when considered necessary. For temperate regions of the country these tunnels are proving to be boon for raising crops for use as fresh as well as seeds.

The experience gained so far suggest plastic mulch, fertigation and low plastic tunnels suit Indian rural horticulture farmers. A combination of these is considered

Fig. 3. Strawberry crop in walk-in tunnel

best for the crop and yields better return to farmers.As stated earlier besides above there are other protected structures such as high roof tunnels with ventilation, insect proof net houses, shade net houses, naturally ventilated poly house, climate controlled greenhouses, rain shelter, plastic wall or straw wall which have proved successful to increase farmers income. Some of these structures are expensive and should be used with adequate prior training to avoid failures. Brief description and experienced gained so far on these is a under.

High Roof Tunnels with Ventilation

These tunnels are similar to walk-in tunnel with suitable size ventilation at the top to facilitate escaping the hot air (Fig. 4). These are suitable for cucumber, capsicum, tomato, gerbera and carnation production.

Fig.4. Carnation production in low cost poly house

Insect Proof Net House

Insect proof net house is a closed crop production system with 6 -8 feet height that excludes insect pests via physical barrier of synthetic insect proof 40 mesh, 20 % shade net (Fig. 5). Double layer net houses are also available which lowers the temperature in summer months. Open top insect proof net houses with more than eight feet height have been found suitable in protecting crops from insects and insect vectors.Insect proof net houses are becoming popular to protect crops biostress and abnormal climate.

Fig. 5. Virus free Kinnow saplings in insect proof net house in Haryana

Shade Net Houses

Shade net house are affordable by every farmer and considered as one of the popular technologies to provide development of healthy grafts/ seedlings, potted foliage and flower plants, medicinal and spices crops and hardening for various horticultural crops irrespective of climatic conditions. Shade nets are available with different shade percent, 20, 40, 70 andcolour. Shade net houses are made keeping in view the requirements of kind of crop to be raised generally with 6 to 8 feet height (Fig. 6).

Fig. 6. Tomato and cauliflower nursery under shade net – Sultanpur district, Uttar Pradesh, India

Naturally Ventilated Poly houses

These are naturally ventilated green/poly houses with single span and total central height of 5 meters, side ventilation of 3 meters with roll-able poly-cover with or without roof ventilation and double door entry. Such poly houses are found suitable for round the year production of crops depending on the geographical area. There can/should be multi-span naturally ventilated poly house with a central height of 6.5 meters, gutter height of 4.25 meters, side ventilation of 1.5 meters (Fig. 7). Generally multi-span poly houses are considered more suitable and economical for raising crops. Naturally ventilated poly houses have been found suitable for cultivation of large number of vegetables, flowers and strawberries besides raising their nurseries in many parts of the country.

Fig. 7. Gerbera under poly house of Mr.Moinuddin's field at Barbanki, Uttar Pradesh

Poly house with Pad and Fan System

These poly houses unlike naturally ventilated poly house has fan and pad system to regulate temperature and humidity. They have generally height of 4.5 meters with common side and top ventilation. These structures are clubbed with exhaust fans and cellulose cooling pads of 1.8 m in height and 150mm thickness (Fig. 8). The cost of construction, running and maintenance is high. Lack of assured power supply becomes a limiting factor for such structures in our country.

Fig. 8. Roses under greenhouse

Hi-tech or Climate Controlled Greenhouses

Hi-tech green houses are climate controlled structures. Green houses have a variety of applications, the majority being, off-season growing of vegetables, foliage and flower plants, planting material multiplication and acclimatization, fruit crop growing for export market, seed production, plant breeding and new varieties and hybrids development. These are available in different sizes and constructed as per requirement. The sizes vary from as small as 100 sq. m to 10,000 sq m and more. Here most of the parameters temperature, light, humidity, fertilizer, irrigation are sensed and corrected as per program through auto control systems. These can be fully or partially automated. These are considered, based on experience, very good and essential structures for nursery multiplication of horticulture crops (Fig. 9).

Fig. 9. Multiplication of rootstock and seedlings in soilless medium in Haryana and tomato in Uttar Pradesh, under Hi-tech greenhouse

Rain shelters

Rain shelter, a low cost naturally ventilated poly house is found ideal for off-season vegetable cultivation in Kerala, Andaman and Nicobar Islands, north east region and other high rainfall areas of the country (Fig. 10) . Off-season cultivation of vegetables by utilizing low cost protected structures like rain shelter can be considered as a profitable enterprise besides protecting crop nurseries from high rain during monsoon months. Such structures are boon for horticulture production in high rainfall areas of the country.

Fig. 10. Rain shelters for crop production

Polyhouse Cultivation Achievements

The yield under poly house cultivation can be achieved to the level of 3-8 times as compared to the open crop cultivation (Singh et al. 2014). Various trials conducted at agro research centres in northern India indicate that capsicum (planted in mid-September), cucumber (planting – mid October) and tomato (November planting) under poly house produced 1060kg, 1460 kg and 1530 kg per 100 square meter. The duration of these crops were 4- 9 months and more than 90% of total yield were obtained during off-season (during winter before the start of summer) which fetches significantly higher market price (2-4 times than normal season). Further, the crop duration can be extended up to the July –August with the application of micro irrigation and fertigation and yield can be achieved to the level of 20-25 kg/m2. Therefore, it is possible to harvest a single crop round year with minimum additional inputs and higher income can be generated. Further cut flowers like carnations, gerbera, lily, rose, orchids, anthurium etc. can be grown under poly houses/ net houses giving high returns and better quality produce. The potential of floriculture under protected cultivation is huge for Indian and global markets. The cost of construction of poly house depends on location of site, size and shape of poly house, poly house structure (wooden or GI/ Steel) and types of poly house (naturally ventilated or environmental controlled). The cost of bigger naturally ventilated poly house (1000 m^2) ranges from Rs.800 to 900 per square meter whereas the environmental controlled poly houses require 2 to 3 times investments over previous one depending on the automation gadgets installed. The per unit area construction cost of smaller size poly houses are more as compared to larger poly house. Similarly the cost of cultivation in larger poly house is significantly lower than smaller poly house. It is possible to get back the investment on poly house within a period of 3 to 5 years period. If a entrepreneurs /cultivator go for poly house for nursery production of high yielding vegetables in an area where large scale vegetable cultivation is done, in such condition he can get back his investment within 2-3 years by providing quality planting materials to vegetable or flower growers. The success of the poly house/ net house project depends upon the scale of the project.

In India, only one per cent of total floriculture is equipped with protected cultivation techniques, whereas agriculturally advanced countries such as Netherlands, Italy, Spain, France and others have 55-70 per cent flower cultivation area covered under protected cultivation.

Protected cultivation, besides increase in yield, saves water up to 50 per cent, compared to open field flood irrigation, reduction in cost of fertilisers, labour etc. Undulating terrains, saline, water logged, sandy and hilly lands can also be brought under productive cultivation using protected cultivation. A poly house in an acre would approximately cost anywhere between ¹ 25 and 30 lakh. This would last for at least 15 years. The yield per acre in the first year would be in the range of ¹ 75-80 lakhs. There is a component of more than 30 per cent subsidy available from the Government.

Experiments conducted at division of vegetable science at Indian Agriculture Research Institute, New Delhi on low cost poly houses have reported the following economics.

The low cost polyhouses which were used for raising nursery, the same type of structures was utilized for raising crops during winters. The high value crops like cherry tomato, gherkin, bitter gourd (gynoecious) and cucumber (parthenocarpic) were grown during November second fortnight. The temperature inside polyhouse was 6-10 degree celsius higher than outside. The cold waves during December-January did not enter the structure and the growth of the plants were normal. All the recommended cultivation practices of these crops were followed to raise a good crop. Harvesting of gherkin started from last week of January. Gherkin recorded Rs. 43,500/- and Rs. 59,000/- profit from 1000 m2 area during first year and second year respectively. Harvesting of cherry tomato was started from mid-February and net profit of Rs. 33,750/- during first year and Rs. 50,000/- during second year was recorded. In Bitter gourd (gynoecious) a net profit of Rs. 23,750/- was recorded in first year and Rs. 40,000/- during second year onwards. Parthenocarpic cucumber recorded Rs. 37,000/- profit during first year and Rs. 52,500/- during second year onwards (Reddy 2016).

Size of structure (10m (L) x 5m (W) x 7' (H)) = 50sq.m.
No. of seedlings 8000 (polybags) + 7000 (portrays) = 15,000/-
Seedling @ Rs.2/- = Rs. 30,000/-
Investment cost (polyhouse, polybags, protrays) = 15,500 + 5,000 = Rs. 20,500/-
Net profit 1st year (30,000 – 20,500) = Rs.9500/-
Net profit 2nd year (30,000 – 5000) = Rs.25000/-
Net profit 3rd year (30,000 – 6000) = Rs.24, 000/-

During 2015 Department of Soil Science and Water Management, Dr Y S ParmarUniversity of Horticulture and Forestry, Nauni, Solan reported comparison of the productivity under open field and poly house cultivation of capsicum, tomato, cucumber, beans, peas, coriander and spinach It is given in the following table which is self-explanatory indicating to 59 to 414 per cent increase in productivity.

An extensive study has been reported in 2010 in the state of Punjab on cultivation of vegetables under net house. It has indicated that gross return was highest for tomato with Rs 1,97,828/- and least in case of pea with Rs 27,875/- The return over total production cost was maximum in case of tomato that is Rs 167419/- and least in case of pea that is Rs 8913/-. The growing of chili is expensive costing Rs 36980/

Table 1. Effect of poly house on productivity of vegetable crops as compared to open cultivation

	Open cultivation Mt/ha			Poly house cultivation Mt/ha			
Crop	Min.	Max.	Average	Min.	Max.	Average	% increase
Capsicum	25	30	27.5	90	150	120	336
Tomato	40	45	42.5	180	250	215	406
Cucumber	15	20	17.5	80	100	90	414
Beans	10	15	12.5	24	32	28	124
Peas	10	15	12.5	20	25	22.5	80
Coriander	10	12	11.0	15	20	17.5	59
Spinach	10	15	12.5	20	25	22.5	80

Source: Department of Soil Science and Water Management, Dr Y S Parmar, University of Horticulture and Forestry, Nauni, Solan 173 230, India

- per acre and pea was least expensive costing Rs.18962/- per acre. The vegetable rotations studied were: tomato-pea; chili-pea; tomato-capsicum-potato; capsicum-chili; tomato-capsicum; capsicum-paddy; chili-paddy; tomato-capsicum-pea; tomato-chili and tomato-capsicum-chili.

Haryana Agriculture University, Hisar has reported production of 302 t/ha, of tomato, 211t/ha of capsicum and 115 t/ha of cucumber per crop cycle under naturally ventilated poly house.

A farmer in Alwar district of Rajasthan grew parthenocarpic cucumber (Kian and Hiltan) in 1000 sq. m. naturally ventilated poly house from September 2011to January 2012 and January2012 to May 2012. He harvested 50 q and 75 q fetching him Rs 1.5 lakh and 2.6 lakh, respectively, as per IARI, New Delhi report.

2. *Israel in Rajasthan:* Sh Khema Ram a farmer from Rajasthan, trained in Israel, is having poly houses in 7.5 acres with annual turnover of Rs one crore only. He started protected cultivation in 4000 sq. m few years back. (*https://www.gaonconnection.com/badalta-india/the-farmer-of-rajasthan-khemaram-made-his-village-a-mini-israeli-turnover-of-10-million-annually)*

3. Classic Floritech, Sirmor (HP) 2016-17. Mr Mohammad Mushtaq with the support of NABARD established poly house in 03 acres during 2008. He is growing roses about one lakh plants worth annual net profit of Rs 10.29 lakhs. He is a known and renowned floriculturist in India on date having large acreage of net houses and polyhouses for flower production. He is helping farmers to adopt protected cultivation in Himachal Pradesh, Punjab and Haryana.

4. *Sardar Surjeet Singh Virk;*in a village Pakka Kheda, Karnal he had 05 acres of net houses added another 02 acres in 2017 with support of NABARD. He is growing cucumber and capsicum in these net houses with net income of Rs 4.5 lakhs (from 5 acre) per acre annually.

5.*Dr B S Rana, Narayangrah, Ambala:* He has 06 acres of net houses and growing mainly medicinal plants particularly stevia (meethitulsi) since 2013 and earning net profit of Rs 7.3 lakhs per acre annually.

Above success stories prove that protected cultivation is profitable prideful profession but construction of poly houses require substantial investment for which following agencies provide subsidies/loan. Cost and benefit ratio of growing tomato (4 months) and capsicum (five months) in Andaman and Nicobar Islands has been reported 1:2.5 and 1: 11.2, respectively. In Karnataka the total returns and net returns from capsicum production under protected conditions from 0.25 ace unit were Rs 1 54734 and Rs 1 15279, respectively. The B: C ratio of capsicum production under protected conditions was 3.92.

To assess the costs and benefits drawn by the farmers through crop cultivation in polyhouses, a study was conducted in Kullu and Mandi districts of Himachal Pradesh, India. A sample of about 50 poly house units of varied sizes was randomly selected in five developmental blocks of two districts. The total cost of construction was Rs. 100500, Rs. 216250 and Rs. 481600, respectively for poly houses of 100 sq.m., 250 sq. m. and 500 sq. m. and farmers had to invest only 20% of the total cost, rest came through subsidy. It was observed that about 85 per cent of the farmers grew capsicum, tomato or cucumber in their poly houses as main crops and exotic vegetables like iceberg lettuce, pokchoi and celery as covering crops. It was estimated that a farmer could have net returns up to Rs.1.42 lacs per annum from a 500 sq. m. poly house.

CONCLUSION

Above experience indicate that protected horticulture is potential technology for higher and quality production even under unfavourable climate**.** Best options on date for out scaling protected cultivation among small holder farmers are:

- Plastic mulch and fertigation
- Plastic tunnels both low as well as walk-in tunnels are most suitable for temperate climate with modifications according to climate of the place and raising early cucurbits in northern plains. Rain shelters have been found successful in high rainfall areas like Kerala.

- Net house + plastic mulch + fertigation for large number of crops like tomato, cucumber, capsicum; chrysanthemum, lilies, roses, gerbera, anthurium, foliage plants; stevia, basil and others.
- Climate controlled greenhouses are needed for raising plant nurseries to meet huge seedlings requirement of vegetable and flower growing clusters both under open field cultivation and cover besides ornamental/ foliage plants multiplication.
- Inputs and guidance for above from reputed private and public sectors are must.
- . The crops successfully grown in these structures are cucumber, tomato, capsicum, roses, chrysanthemum, lilies, strawberry, leafy vegetables and herbs.
- Bamboo stacking in cucurbits and tomatoes + plastic mulch + fertigation

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Review Article

Potentials and Limitations of Multifunctional Microbial Stimulants in Sustainable Agriculture

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Soil microbes play multiple beneficial role in rhizosphere of plants, for example, plant growth promoting microbes by fixing or solubilizing plant nutrients, by producing plant growth hormones, biodegradation of agro waste, bio-control of pest and diseases and bioremediation of toxic substances. The soil microbial biodiversity and populations are declining rapidly from the agro-ecosystems due to intensified cropping, use of toxic agrochemicals, decreasing soil moisture, increasing soil temperature, unfavorable changes in soil pH and deposition of salts in the upper crust. Due to low soil organic matter and soil quality degradation the natural enrichment of native soil microbial population needed for multiple nutritional, disease management and other ecosystem services may not be regenerated automatically. Application of multiple strain consortia of beneficial soil microbes isolated from the soil of different conditions may help to sustain and enhance the crop productivity in a sustainable way without use of synthetic agrochemicals. The stability and ecological succession of inoculated microbes in the native and non-native agro-ecosystem have not been understood as yet which is essential to develop stable formulations of new generation bio-inoculants.

Key words
Soil microbes, Stimulants, Agro-ecosystem, Sustainable agriculture

INTRODUCTION

Nutrients play most important role in sustaining life on this earth for both plants as well as animals. Plants take its nutrient from lithosphere and atmosphere, whereas animals are dependent on plant for its most of the nutrient requirements directly or indirectly. All plants take up their nutrients in inorganic form from the soil even if it is added or available in soil as organic nutrients. Plants require a sufficient, but not excessive supply of essential nutrients for its optimal productivity (John et al., 2016). An insufficient supply of a mineral nutrient whose requirement is in large quantities for the plant or mineral elements with low phyto-availability in soils often limits plant growth and productivity (Oliver and Gregory, 2015). Most of agricultural soils which possess sufficient phyto-available N, P or K and various micronutrients to satisfy the requirement of rapid growth and productivity of plants during their vegetative and reproductive phases are rare mainly because of continued cycles of intensified crop cultivation. Hence, these elements are supplied as fertilizers in both intensive and widespread agricultural systems. Certain inorganic fertilizers like urea, DAP, NPK etc. (also known as synthetic fertilizers) are manufactured chemically. Today crop productivity has increased significantly by the green revolution practices in many countries including India primarily due to the hybrid seeds, exogenously loaded chemical fertilizers and pesticides and flood irrigation etc (Purushothaman et al., 2012, Kochupillai, 2016). Though the fertilizers increase crop productivity, it also causes certain adverse effects on human health and soil biodiversity, especially when loaded in excessive amount (Diana et al., 2015). Nitrate, nitrite and other reactive nitrogen species as well as its derivatives like Nitrosamines; the transformed products of nitrogen fertilizers are poisonous, mutagenic and carcinogenic for animals and humans if get accumulated in food stuff or get contaminated with water bodies (Ziarati et al., 2018). Now it is realized that the chemical supported intensive agricultural practices are no more sustainable and has caused serious threat to the agro ecology and human health due to loss of soil fertility and contaminations of soil, water, air and food products with the residues of toxic chemicals. In addition, emissions of NOx and volatization of NH_3 provide additional warming potential of the Green House Gases (GHGs) considered as a cause of global warming and climate change (Cui et al., 2013).

Looking towards the suitable alternatives for chemical fertilizers, and pesticides that can maintain the productivity of plants without causing any adverse effect to the ecosystem is a major concern of Agricultural sustainability today. Farm yard manure (FYM), Vermicompost, no tillage farming, Zero- Budget Natural Farming (ZBNF) use of biopesticides and Non Pesticide Management (NPM) and application of bio-fertilizers are seen as possible alternatives to sustain soil microbial biodiversity which help to maintain sustainability in agro-ecology (Bishnoi and Bhati, 2017). In the ZBNF, soil is supplemented with the microbial inocula like Beejamruth and Jeevamruth to accelerate the propagation of native soil micro flora beneficial to soil enrichment. Application of the selected beneficial soil microbes by seed priming or soil amendment as bio-fertilizers or biopesticide possessing single microbe or microbial consortia, is another ecological way to provide additional nutrients for the crops. The microbial formulations commonly known as bio-fertilizers and bio-pesticides are not very popular due to lack of authenticity and continuous effectivity in different agro-climatic conditions after their inoculation (Kong et al., 2018). The efficacy of microbial biofertilizers often gets limited due to lack of adequate understanding of Plant-microbe interactions changes in rhizospheric microbial flora in the given agro-climatic conditions after application of new microbial formulations and the ecologically succeeding population of the amended microbes in the rhizospheric regions of the crop plants (Malusà et al., 2016).

MICROBES AS NUTRIENT PROVIDER

The effect on soil health due to the adverse effects of soil especially the response of amended soil microbes to the agrochemicals available in soil have been not studied adequately (Mueller and Sachs, 2015). It is found that the plant growth promoting rhizobacteria (PGPR), mycorhyza and cyanobacteria etc. can play multiple role in promoting plant growth, protecting them against pathogens, helping in the biodegradation of non-toxic and toxic waste available in the soil and providing certain macro and micronutrients by mobilizing it from air or insoluble forms in the soil. An understanding of beneficial interactions of plant microbiome and their beneficial attributes could have multiple benefits towards sustainable agriculture. Recently, a great emphasis is given on decoding of microbial diversity associated with plants from diverse habitats (Bhardwaj et al., 2017). In rhizosphere amendments of beneficial microbes of different groups including archaea, bacteria, and fungi especially from the extreme environments (acidic, alkaline, drought, pressure, salinity, and temperatures) can be isolated and their inoculants in rhizosphere of crop plants suffering from such stresses can provide a climate resilient ecological niche to enhance plant productivity without application of agrochemicals (Verma et al., 2017). In addition to the rhizospheric soil microbes, epiphytic and endophytic microbes which are also associated with plants as well as the microbes growing in the extreme environment may be more useful in restoring the agro-ecology and designing a new rhizospheric soil microbe interaction in a planned way (Ajar et al., 2017)**.**

Rhizosphere is the most complex microbial habitat on the earth, consisting of an integrated network of plant roots, soil fauna, diverse microbial consortia and soil components. The rhizospheric microbes are also influenced by roots through the release of substances that affect microbial activity and characterized as zone of high microbial dynamics (Macnear, 2013). The microbial populations and their activity gradually decrease depending on the distance from the plant roots. Hence the rhizosphere constitutes a niche especially suitable for obtaining more culturable and beneficial microbes for plant cultivation (Lareen et al., 2016). These associated microorganisms play significant role in plant productivity by promoting the supply of nutrients to the plants to ensure their growth and productivity even when amended from outside in adequate amount (Table 1).

Certain selected microorganisms isolated from rhizosphere are often used in the preparation of biofertilizers. Many beneficial microbes have exhibited multifunctional plant growth promoting (PGP) attributes such as N_2-fixation, solubilization of macro and micronutrients (e.g. phosphorus, potassium and zinc), and production of siderophores, antagonistic substances, antibiotic, growth promoting hormones and enzymes for degradation of biological (lignin and protein) and chemical substance (pesticides) (Shen et al., 2016). By understanding the rhizospheric plant microbial interactions, we can predict and manipulate the role as well as composition and function of rhizosphere through designing of a new combination of soil microbes more useful for plant productivity and soil health. It will allow us to design plant-microbe interactions in the rhizosphere that will increase or restore plant ecosystem productivity, improve plant responses to a wide range of environmental perturbations, and mitigate effects of climate change by designing ecosystems for long-term soil carbon storage (Adl, 2016). Microbial as well as organic amendments, root architecture modification, root nodule manipulations, root selective trait transfer, agronomic practices for better root soil association, and genetic manipulations for more root exudation as well as higher nutrient uptake and assimilation could be the various aspects to be adopted as rhizospheric engineering (Ahkami et al., 2017). However, the engineering of rhizosphere with these microbial bio-inoculants provide an eco-friendly technology and bioresource input for the sustainable agriculture and quality food production (Yadav et al., 2017).

MICROBES AS BIOCONTROL AGENT FOR PLANTS

The nutrient supply is not only factor which influence the productivity and growth of plant but it also depends on the protection from the pest which negatively influence it in various ways (Matthias and Jing, 2013). In the era of green revolution for the protection of crops from pest and diseases application of chemical pesticides was adopted under which various weedicide, insecticide, rodenticide, fungicide was produced by multinational chemical companies and aggressively marketed throughout the world. The pesticides

Table 1. Certain beneficial microbes characterized and studied as Plant Growth Promoting microbes and amended in rhizosphere during the crop cultivation

Nutrient and plant growth promoter	Biological pathway	Microbes
Nitrogen	N2 Fixation	*Azospirillum* spp., *Azotobacter* spp., *Azoarcus* spp., *cyanobacteria, Bacillus* spp., *Enterobacter* spp., *Xanthobacter* spp., *Gluconacetobacter diazotrophicus, Achromobacter* spp., *Arthrobacter* spp., *Azomonas* spp., *Clostridium* spp., *Beijerinckia* spp., *Corynebacterium* spp., *Rhodospirillum* spp., *Klebsiella* spp., *Derxia*, spp., *Herbaspirillium* spp., *Pseudomonas* spp., *Rhodopseudomonas* spp.
Phosphorus	Phosphate solublization	*Alcaligenes* sp., *Aerobacter aerogenes, Achromobacter* sp., *Actinomadura oligospora, Bacillus, Pseudomonas, Penicillium and Aspergillus* spp. *Bacillus subtilis, Bradyrhizobium* sp., *Brevibacterium* sp., *Citrobacter* sp., *Pseudomonas* sp., *P putida, P. striata, P. fluorescens, P. calcis, Flavobacterium* sp., *Nitrosomonas* sp., *Erwinia* sp., *Achrothcium* sp. *Penicilliumdigitatum, P lilacinium, P balaji, P. funicolosum., Cephalosporium* sp., *Cladosprium* sp., *Curvularia lunata.,*
Potassium	Potassium solublization	*B. mucilaginosus, Bacillus, Clostridium and Thiobacillus*
Fe	Siderophore production	*Pseudomonas aeruginosa, Gallionella and Leptothrix species*
Zn	Zinc solublization	*Burkholderia* sp., *Acinetobacter* sp.
Auxin	Cell enlargement, root initiation vascular differentiation, apical dominance	*Pisolithus tinctorius,Azospirillum, Rhizobium, Bradyrhizobium, Azospirillum, Gluconacetobacter, Herbaspirillum, Cyanobacteria, Nostoc*
Gibberellins	seed germination, development and reproduction of plants, floral development	*Gibberella fujikuroi, Azospirillum brasilense, Azospirillum lipoferum*
Cytokinins	cell division, chloroplast differentiation, photosynthesis, senescence, and nutrient metabolism	*Azospirillum, Pseudomonas syringae, Agrobacterium tumefaciens, Erwinia herbicola*

Source; Ahemad and Kibret (2013); Kaymak (2010); Prasad *et al.* (2015)

killed certain pests effectively. However, the successive use of chemical pesticides developed dose tolerance in the pest, which resulted in increase of dose at every successive use. The uncontrolled use of pesticide showed various harmful effects i.e. new pests were introduced due to change in food chain, it has brought many species of microbes, plants and animals on the verge of extinction and bioaccumulation of pesticides induced various disease in live stocks and human (Chattopadhyay et al.,2017).The contamination of agro-ecosystem, water and air with pesticides and its residues and many toxic heavy metals have killed many microphytes, earthworms, beneficial insects and birds and it has changed biodiversity composition of the area with predominance of only few tolerant species.

The biological pest and disease control agents including microbes and extracts of certain aromatic and medicinal plants have shown effective alternatives for harmful chemical pesticides against most of plant pests (Table 2). The microbes played a significant role in controlling various diseases without showing any negative impact on nature and health. On the other hand, the applied chemical pesticides and their residues continue to be present in the agro-ecosystems and keep accumulating in the foods having negative impact on the quality of food. Microbes in addition to act as biopesticide have also been reported to degrade certain chemical pesticides. Many microbes are evolving new pesticide tolerance mechanisms and developing capabilities to degrade these chemical pesticides for their own survival (Table 3).

COMMERCIAL FORMULATIONS: LIMITATIONS AND CHALLENGES

Though different microbes which facilitate atmospheric N_2-fixation, solubilization of nutrients (phosphorus, potassium and zinc) and production of plant growth promoting hormones, siderophores, antagonistic substances, antibiotic, and enzymes for degradation of biological (lignin and protein) as well as toxic chemical substance (pesticides) have been formulated commercially and marketed (Nadeem et al., 2015). However, these formulations are not used widely by a large number of farmers and other commercial agricultural producers to replace the agro-chemicals due to the problems of stability of microbial activity and viability of microbes during production, storage, marketing, distribution and application in soil. It has been noted that their efficacy goes down significantly in the agricultural fields (Teresa et al., 2018). Further, living cells are sensitive to

Table 2. Exogenously applied Microbes helping in disease and pest management

Crop	Disease	Pathogen	Possible biocontrol agents
Cereals			
Rice	Blast	*Pyricularia oryzae*	*P. fluorescens Trichoderma spp.*
	Bunt	*Neovossia indica*	*T. harzianum, T. viride, T. virens, T. deliquescens*
	Sheath blight	*Rhizoctonia solani*	*P. fluorescens, P. putida, T. harzianum, T. viride, T. virens, A. niger*AN27
	Brown spot	*Drechslera oryzae*	*T. viride*
	Bacterial leaf blight	*Xanthomonas oryzae*	*Bacillus spp.*
Wheat	Karnal bunt	*Neovossia indica*	*T. viride, T. harzianum, T. pseudokoningii*
	Loose smut	*Ustilago segetum*	*T. viride, T. harzianum, T. Koningii, T. lignorum*
	Root rot	*S. rolfsii, F. oxysporum,*	*T. harzianum*
	Take-all	*Gaeumannomyces graminis var. tritici*	*T. harzianum*
Maize	Charcoal rot, Banded Blight R. solani	*Macrophomina phaseolina,*	*Trichoderma spp.*
Sorghum	Charcoal rot	*M. phaseolina*	*A. niger*AN27
Pigeon pea	Wilt	*Fusarium udum*	*T. viride, T. hamatum, T. harzianum, T. koningii, B. subtilis*
	Seed-borne disease	*Xanthomonas campestris pv. vinae*	*T. viride, T. harzianum*
Chickpea	Wilt	*F. oxysporum f. sp. ciceri*	*T. viride, T. harzianum, T. virens, B. subtilis, A. niger AN27*
	Root rot	*Rhizoctonia solani/M. phaseolina*	*T. viride, T. harzianum*
	Collar rot	*Sclerotium rolfsii*	*T. viride, T. harzianum, P. fluorescens*
	Grey mold	*B. cinera*	*Trichoderma sp.*
	Stem rot	*S. sclerotiorum*	*T. harzianum*
Cowpea	Wilt	*F. oxysporum f. sp. ciceris*	*T. viride*
	Charcoal rot and wilt	*M. phaseolina, F. oxysporum, f. sp. Tracheiphilum*	*T. viride, T. harzianum, T. koningii, T. pseudokoningii*
Soybean	Dry root rot	*M. phaseolina*	*T. viride, T. harzianum*
Mungbean	Root rot	*M. phaseolina*	*T. harzianum, T. viride*
Oil Seed Crops			
Groundnut	Crown rot	*Aspergillus niger*	*T. viride, T. harzianum, B. subtilis*
	Stem & pod rot	*Sclerotium rolfsii*	*T. harzianum, Rhizobium*
	Late leaf spot	*Phaeoisariopsis personata*	*Penicillum islandicum, P. fluorescens, T. harzianum, B. subtilis*
	Root and stem rot	*R. solani*	*T. virens, T. longibrachiatum*
	Rust	*Puccinia arachidis*	*Verticillium lecanii, T. harzianum*
Castor	Wilt	*Fusarium oxysporum f. sp. ricini*	*T. viride, A. niger*AN27
	Grey mold	*Botrytis cinerea*	*T. viride, P. fluorescens*
Mustard	Damping off	*Pythium aphanidermatum*	*T. harzianum, T. viride*
Vegetables			
Bottlegourd	Wilt	*F. oxysporum*	*A. niger* AN27
	Root rot	*R. solani*	*A. niger* AN27
	Collar rot	*Sclerotinia sclerotiorum*	*T. viride, T. virens, B. subtilis*
Cauliflower	Damping off	*Rhizoctonia solani, P. aphanidermatum*	*T. harzianum , A. niger*AN27
	Stalk rot	*S. sclerotiorum*	*A. niger*AN27
Potato	Black-scurf	*R. solani*	*T. viride, T. viride, B. subtilis*
	Charcoal rot	*M. phaseolina*	*A. niger*
	Late blight	*P. infestans*	*Trichoderma sp.*
Tomato	Damping off and wilt	*F. oxysporum, B. cinerea f.sp. lycopersici*	*T. harzianum, P. fluorescens*
	Grey, B. cinerea	*Meloidogyne incognita*	*T. harzianum*
	Root Knot- Meloidogyne incognita	*M. javanica*	*T. harzianum*

Source: Singh (2014); Prasad et al. (2015); Meena et al.(2017)

Table 3. Exogenously applied and native microbes helping in biodegradation of toxic and nontoxic substances

Nature of component	Name of the component	Microbes degrading the component
Toxic	DDT in soil	*Escherichia col., Enterobacter aerogenes, Enterobacter, Escherichia coli, Enterobacter aerogenes, Enterobacter cloacae, Klebsiella pneumonia, Pseudomonas putida, Bacillus species , Hydrogenomonas*
	DDT (activated sludge)	*Pseudomonas sp., Pseudomonas aeruginosa, Micrococcus, Bacillus pumilus, Bacillus circulans., Bacillus sp. , Flavoba cterium sp.*
	Endosulfan	*Pseudomonas sp., Bacillus sp., Flavobacterium sp.*
	Lindane	*B. thiooxidans and Baseathio oxidans, Sphingomona spaucimobilis, Streptomyces sp., Pleurotus ostreatus*
	Atrazine, monocrotophos, alachlor and 4-chlorophenol	*Arthrobacter, Clavibacter, Nocardia, Rhodococcus, Nocardioides, Streptomyces*
	Pentachloronitrobenzene	*Rhizoctonia solani, Botrytis spp., Aspergillus spp., Penicillium spp., Fusarium spp., Sclerotinia spp., Tilletia caries*
	Nitrobenzene	*Pseudomonas pseudoalcali genes* JS45, *Pseudomonas putida* HS12, *Comamonas sp.* JS765, *Pseudomonas mendocina* KR-1, *Pseudomonas pickettii* PKO1, *Cyanobacterium, Microcystis aeruginosa, Arthrobacter sp*. NB1, *Serratia sp*. NB2, *Stenotrophomonas sp.* NB3, *Comamonadaceae , Clostridium spp., Rhodotorula mucilaginosa strain* Z1
	Cypermethrin	*E. coli, S. aureus, P. aeruginosa, B. subtilis, Enterobacter asuburiae, Pseudomonas stutzeri*
	Carbofuran	*Pseudomonas, Flavobacterium, Achromobacterium, Sphingomonas, Arthrobacter*
	Carbendazin	*Pseudomoans*
	Lambda-cyhalothrin	*Klebsiella sp., Pseudomonas oleovorans*
	Fenvalerate	*Bacillus cereus , Pseudomonas viridiflava, Arthrobacter sp , Flavobacterium sp. Pseudomonas sp., Phanerochaete chrysosporium, Phlebia sp., Bjerkandera sp.*
	Endrin and Aldrin	*Trichoderma viridae, Pseudomonas sp., Micrococcus sp., and Bacillus sp.*
	Dieldrin	*Pseudomonas sp.*
Non-toxic	Lignin	*Cerrena unicolor, Phanerochaete chrysosporium, Postia placenta, Armillaria melea, Pleurotus spp., Trametes versicolor, Agaricus bisporus, Serpulala crymans, Ustilago maydis, Xylaria spp.,Brucella, Ochrobactrum, Sphingobium , Sphingomonas genera, Streptomyces viridosporus, S. paucinobilis , Rhodococcus jostii , Pseudomonas fluorescens , Ps. putida , Enterobacter lignolyticus , Escherichia coli.*

Source: Verma *et al*. (2014); Nayak *et al*.(2018)

sudden changes and extreme agro-climatic conditions, hence may not compete with the existing and adopted native soil microbes after application in new agro-climatic conditions in such changing or extreme conditions. Only few studies are available on the succession and survival of inoculated microbes in the agricultural fields (Meena et al., 2017), though such studies are very important for understanding the role of applied soil microbes in plant productivity and maintenance of soil fertility.

To increase the stability and efficacy of microbial inoculants different type of carriers and different combinations of compatible microbes with large microbial diversity can also be used. It has been noticed that microbial consortia with diverse species richness may be more stable than a single species or closely related few microbes (Zomorrodi et al., 2018). Similarly, availability of soil organic matter is very crucial for the activity of amended microbes in the soil inhabiting them (Wang et al., 2017). We have reported that organic matrix based granules containing microbial bio-fertilizers give very promising results in terms of efficacy of bio-fertilizers in experimental plots for the multiple crops including rice and wheat cropping system (Sharma and Singh, 2011; Kumar et al., 2015, 2016).

In addition to the technical and technological deficiencies for production and marketing of authentic and effective microbial formulations for control of diseases and pests through non-pesticidal management for biocontrol, bio nutrition of plants by microbial amendments and biodegradation of toxic and nontoxic organic substances, the lack of quality control mechanisms and user's education on multiple toxicity of agrochemicals and available alternatives are also major constrains for its non-acceptability in the farmers at large scale. The economic size of centralized agrochemical production industries and their multinational nature influence the market and the entire extension and distribution channels. The production of microbial inoculants for various purposes can be done on small scale even, if market giants are not entering into it. The localized production by small scale or medium scale cottage industries can save transportation cost and marketing related expenditure (Bashan et al.,2014). The local industrial units based on production of these ecological agro-inputs can provide a significant quantum of jobs to the skilled, semi-skilled and un skilled youth of rural, peri-urban and urban regions.

CONCLUSIONS

Though, rhizospheric engineering with inoculated microbial consortia for multiple agronomic benefits can enrich and even modify the natural microbiome of the soil it can also createnew species diversity and species dominance derived by the ecological succession of the dominant microbial inoculants which may be beneficial to the specific agro-ecosystems being climate resilient and more suitable for the new cropping needs. Biodegradation of nontoxic animal and plant waste can enhance soil organic carbon pool on one hand, and biodegradtion of toxic agrochemicals e.g. pesticides, as well as absorption of heavy metals on the other, can enhance the population of native and inoculated microflora and funa of the soil otherwise detoriated or destroyed by the presence of toxic substances in soil and water. The major concern with the inoculation of non-native microbes may be related to dominance of certain exotic species which may suppress the growth and activity of the native rhizospheric microbes. This aspect is also required to be addressed adequately during the studies and application in rhizosphere engineering projects. It is to be understood that the native microbial population in soil as well as in rhizosphere may not be the same all the time due to frequent agro-climatic changes and emerging threats of global warming and climate change. The inoculated microbes, however, may modify the composition and function of rhizosphere, which can be designed carefully as per the emerging needs of the new agro-climate situations and new cropping systems. The intervention of technology and innovations should not be always seen as a factor causing the negative impact on the conservation of soil biodiversity and practices of the ecological agriculture. The new soil microbial diversity can be in some conditions, more suitable to the new requirements of the changing agro-climatic conditions and emerging needs of the new combination of crops. Our concern should be more towards enhancingtotal soil microbial diversity, carbon sequestration capacity and multiple ecosystem and economic services of the below ground and above ground agro-ecosystems.

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Review Article

Engineering and Agronomic Interventions to Enhance Water Productivity in Rainfed Areas

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Irrigation sector, Rain fed farming, Cultivable land, Rain water management, Factor productivity

The challenge of producing food for a rapidly increasing population is daunting. In spite of huge investment in irrigation sector, rain fed areas contribute a major proportion of agricultural production of India. As it is not possible to use the entire cultivable land under irrigation due to practical and resource limitations, there is an urgent need to improve the productivity of the existing cultivable areas. In the present paper, we discussed herein about the problems, prospects and significant options available to improve productivity of rain fed areas. Research areas which may be taken up for experimentation in the rain fed farming development and thereby improving the total productivity of rain fed farming have also been discussed.

INTRODUCTION

Rain fed agriculture plays an important role in Indian economy as the scope for expansion in irrigated area and yield improvements is limited. Substantial portion of food production should be shifted and developed under rainfed agriculture. Most parts of the country do not receive sufficient rainfall and limited rainfall can not fulfil the requirement of most of the cultivated crops all over the country. In rainfed areas, problems with monsoon like low rainfall, high variability of onset and distribution and prolonged dry spells has been affecting crop growth and yields significantly. Research and extension work to benefit the farmers practicing irrigated agriculture has resulted in increasing the gap in productivity between irrigated sector and rainfed sector over the years. For example in 1980's the productivity of irrigated crops has grown by six times faster than that of the rainfed areas, which was virtually stagnated in that decade. In India, out of the net sown area of 136.8 M ha, rainfed area amounts 93.1 M ha (68 %) distributed in 177 districts. Rainfed crops account for 48 per cent area under food-crops and 68 percent of the area under non-food crops. In terms of output, 80 percent of the coarse cereals, 50 per cent of maize, 65 per cent of pulses, 81 per cent of groundnut, 88 per cent of soybean and more than half of the cotton output of the country are accounted in rainfed cultivation. Nearly 50 per cent of the total rural workforce and 60 per cent of cattles of the country are located in the rainfed areas (Anonymous, 2001). Besides being economically important, rainfed farming is also important for the nation in terms of bio-diversity and nutrition. Rainfed farming systems are by nature diverse and various crops which are becoming out of cultivation day by day are cultivated under rainfed system. This is particularly with regard to minor millets like little millet, kodo millet, Italian millet and Barnyard millet. The widely grown rainfed crops (besides the above mentioned minor millets) like jowar, bajra and finger millet are nutritionally superior to widely consumed rice and wheat.

Ecologically, rainfed areas are diverse, ranging from deserts in plains to humid rainfed areas in hills and mountain ecosystems. Rainfed agriculture zones of India are shown in Fig.1. Traditional farming is practiced and the crops mature at different times. Agriculture and animal husbandry are not practiced in isolation but in combination as agri-silvicultural, agri-pastoral and agri-silvi-pastoral systems. The cultivars may be individually poor in productivity but collectively the intercropping and mix-cropping are reasonably productive. Rainfed agriculture is generally characterized by low productivity, decrease in agricultural intensification, instability in production and the farmers' income.

Rainfed agriculture is constrained by harsh climates, erratic rainfall patterns, low soil productivity and poor socio-economic conditions of the farmers. The degree of limitations, constraints and potentials of rainfed areas vary over a wide range with the landscape characteristics, climatic factors (precipitation, and micro-climate) and socio-economic factors (ethnicity, type of economic activity, resource management pattern etc.). The problems associated with rainfed agriculture are more acute in degraded lands, which form a sizeable part of rainfed areas; almost fifty per cent of the land in India today is classified as degraded. Judicious management of whatever water resources are available is the key to improvement in rainfed agriculture.

Necessity of Research on Rainfed Agriculture

The different strategic reasons for applying research on rainfed agriculture are as follows:

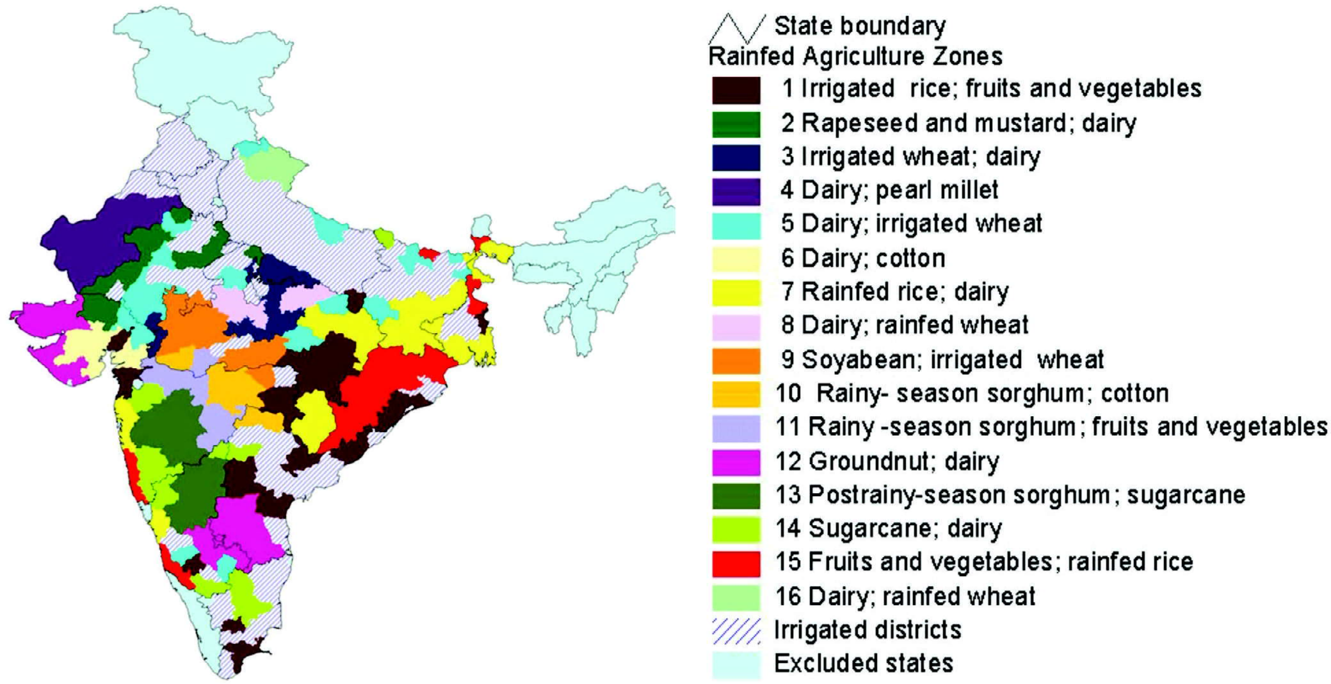

Fig.1: Rainfed agriculture zones of India

- Since the prospects for continued expansion of output from the irrigated areas are limited, other logical option towards improving food security should be focused through rainfed agriculture.
- The land use pattern is changing. Rapid industrialization and urbanization are impinging on fertile agriculture lands, and mainly on irrigated areas which again alarm us to shift towards rainfed agriculture.
- Rainfed areas support very fragile and extremely useful ecosystems. With the growing demand for agricultural land, the pressure on rainfed areas will be increased, which require a proper management of these fragile areas in a sustainable manner.
- The focus on rainfed areas would be an important strategy to support resource poor communities and help them to sustain their lives with more resources.

Increasing Water Productivity in Rainfed Areas

Water productivity refers to economic production per unit of water use. It may be expressed as Mg/m^3 or Rs/m^3 of water use. Basically there are three ways to strengthen water resources and increase water productivity in rainfed areas:

A. Rainwater Management

Rainwater harvesting and its judicious recycling for agricultural production, soil moisture conservation are the important issues in rainfed areas. Rainfall is highly erratic in time and space. Moreover, probably due to global warming, the extent of rainfall is showing declining trends. Soil moisture at the time of sowing *rabi* crops even in high rainfall (>1500 mm) areas is not sufficient for seed germination. During growth phase, crops may suffer from drought at any growth stage due to erratic rainfall pattern and for want of irrigation water. Small-scale rainwater harvesting can bridge intra-seasonal dry spells and stabilize food supplies in periods of poor rainfall. If there are cost-effective ways to store water before critical crop stages and apply it when the rain fails in these critical stages, crop production can be considerably increased. Small-scale farming can be productive in marginal rainfed areas, if supplementary irrigation is available to overcome short-term droughts which are critical to the crop and reduce yield considerably.

The essential components of water management in rain fed areas are:

1. Rainwater harvesting
2. *In situ* soil moisture conservation
3. Efficient utilization of conserved/harvested rainwater through improved agronomic practices.

Rain is the primary source of water. Other natural sources of water, called the secondary water sources, are rivers, streams, lakes, ponds, wells, water springs, groundwater aquifers etc. which draw water from rains. Water harvesting, therefore, is a broad term that includes harvesting of rain water as well as from secondary water sources.

Rainwater harvesting is the process of collecting, concentrating and improving the productive use of rainwater and reducing unproductive depletion. The basic principle of rainwater harvesting is to 'catch water where it falls'. This often involves collecting rainwater from catchments and channeling the runoff and using it to increase the available water in a relatively smaller growing area. About 10-14% of total rainfall, depending on soil and rainfall characteristics may be lost as surface runoff. Rainwater harvesting is done both, micro and macro-catchment basis. In micro-catchment systems, water is collected from land adjacent to the growing area, while with macro-catchment systems large flows are diverted and used directly or stored for supplementary irrigation.

Rainwater harvesting can be done in different ways:

- Capturing runoff from rooftops
- Capturing runoff from local catchments
- Capturing seasonal floodwaters from local streams
- Conserving water through watershed management

i. *In situ* rainwater harvesting

- There are several options for harvesting rainwater *in situ*: to construct thick, strong, raised bunds to impound rainwater *in situ,* to
- grow crops in ridge-furrow system and to
- adopt raised-sunken bed technology; cultivate high water requiring crops like rice in sunken beds and low water requiring crops (maize, soybean, vegetables etc.) on raised beds, to on terraced lands, grow crops requiring well drained conditions on upper terraces (maize, soybeans, vegetables etc.) and high water requiring crops (rice) on lower terraces where run-off concentrates. Divert water from upper terraces to lower terraces and to adopt land shaping in such a way that rain water concentrates at the place where crops are grown.

Under Palampur conditions Sharma (2003) found a raised: sunken bed ratio of 1.5:1 ideal for rice-based cropping system (Table 1). Beds are semi-permanent in nature and do not require frequent recurring expenditure on their maintenance. Raised beds are also suitable for operations with animal drawn implements.

Table 1. Effect of raised-sunken bed system on crop yields

Raised: sunken bed width ratio	Rice yield (Mg/ha)		Maize yield (Mg/ha)	
	1999	2000	1999	2000
0:1 (control)	3.02c	3.40c	0.94b	0.23b
0.5:1	3.49b	3.78b	1.52a	0.47a
1:1	4.16a	4.01b	1.57a	0.41a
1.5:1	4.22a	4.56a	1.49a	0.35a

Means in a column followed by a common letter do not differ significantly at 5% level by DMRT

Source: Sharma (2003)

ii. Water harvesting in farm ponds

The runoff water from fields or water flowing from other sources like springs, small streams cannot serve as water source for irrigating crops due to their slow flow rates but can be effectively stored in suitable small or big reservoirs. Small ponds may also be used as auxiliary water reservoirs in which water is stored during lean period and used as and when required by the crops. The provision of a small pond in one corner of a field to collect runoff during high-intensity rains and its utilization as life saving irrigation or during critical periods of the crop is an age-old practice. Many scientific innovations, however, have been made to improve the efficiency of water storage farm ponds.

Small ponds are ideal for small and marginal farmers who have small and fragmented holdings. In addition, they do not require elaborate management skills and resources. Different types of farm ponds (shape, size, mode of construction) may be constructed at a suitable location in the farm. Small farm ponds may be divided in to three categories:

a. Dug-out small farm ponds and constructed on flat lands
b. Ponds constructed by making barriers and constructed in low-lying areas or natural depressions or small streams.
c. Dug-out ponds constructed by making barriers and constructed on lands with mixed topography.

Suitable lining material may be used to check/reduce seepage losses in farm ponds. The ponds may be lined with polyethylene sheet (covered with soil or bricks or round boulders etc. to protect it against UV sun-light), silpauline sheet (UV resistant), bitumen, cement-soil lining, cement-concrete lining, RCC etc. The cost and longevity of structure will depend on the lining material used. Relative cost incurred on lining farm ponds with different materials as shown in Table 2 gives an idea to a farmer as to which material lining is best suited to him.

Table 2. Cost of construction of dug-out farm ponds with different lining materials

S. No.	Lining material	Cost (Rs/m^3 water harvested)
1.	Cement-concrete lining	709
2.	Bitumen lining	575
3.	Black polyethylene sheet covered with bricks	419
4.	Silpaulin sheet (UV resistant)	348
5.	Black polyethylene sheet covered with soil	277

Source: Sharma and De Datta (1994)

Larger ponds can be made by constructing dam at the upper catchment area of a creek. Water harvested in ponds can be used for irrigation and livestock drinking water. Water harvesting in larger ponds is practiced on community basis.

It involves proper planning and sincere participation of the inhabitants of the catchment and command areas. It may form a part of integrated watershed management involving participatory approach.

B. Soil Management

The objectives of soil management in rainfed areas include shaping of soils to retain maximum rainwater, improving water holding capacity of soils, decreasing evaporation losses, improving soil fertility and conserving soil resources against water erosion. Following are some of the technologies recommended for rainfed areas:

1. *Land shaping*

On gentle sloping of lands, minor leveling of individual fields with minimum cut and fill is an effective method of soil and water conservation. Each field should be provided with a suitable outlet for drainage of excess water. On level lands the individual fields should be provided with suitable bunds to retain the rain water *in situ.*

Sowing of crops in furrows rather on a flat bed also improves moisture conservation and enhances crop yield. In a field experiment, maize sown in 12-15 cm deep furrows gave 25-31% higher grain yield than maize sown on a flat bed (Table 3).

Table 3. Comparison of maize yield sown on flat beds and in furrows

Sowing method	Maize yield (Mg/ha)		
	1986	1987	Average
Furrow sowing (N-S direction)	52.1	35.6	43.9
Furrow sowing (E-W direction)	48.3	33.5	38.2
Flat sown maize	40.0	26.3	33.2
LSD (0.05)	5.6	6.5	

Source: Sharma (2003)

2. *Carbon sequestration in soils*

Carbon sequestration is being considered as a panacea for sustaining soil health, , in addition to conserving soil moisture and protecting environmental pollution. Organic matter plays three important functions: nutritional function (supplies essential nutrients), biological function (food for microbes), and soil physico-chemical function (improvement in soil physical and chemical properties).

Water holding capacity (WHC) and available water capacity (AWC) of soils are directly linked to SOC (Sharma and De Datta, 1994). Barzegar *et al.* (2002), Evrendilek *et al.* (2004) and Hati *et al.* (2006) reported that soil water retention at field capacity (33 kPa suction) and permanent wilting point (1500 kPa suction) has highly significant positive correlation with soil organic carbon. Organic matter improves WHC of soils by improving water retention pores (through improved aggregation) and specific surface area of soils. The WHC of organic matter itself is high. Thus, when added to soil, OM dilutes material of low water retention with that of high retention. Unger (1975) observed an increase in the available water capacity of soil by about 1.8% (volume basis) for each per cent increase in OM for soils ranging in texture from sandy to clay. Joe (1990), based on data from 144 soils, concluded that every 1% increase in OM increased field capacity and permanent wilting point by 2.21 and 1.01%, respectively.

Recycling of organic residues (FYM, compost, green manures, crop residues, waste plant residues, industrial wastes etc.) in to soils should be encouraged. Conservation tillage is another option for improving SOC contents.

In a long term field experiment conducted by Sharma and Bhushan (2001) with rice-wheat cropping system, ten annual additions of lantana biomass at 10-30 Mg/ha (fresh biomass) significantly improved SOC, AWC and non-limiting water range (NLWR – a single value soil physical index; higher the value better is soil physically for plant growth) (Table 4).

Table 4. Effect of ten annual additions of lantana biomass on soil organic carbon (SOC), plant available water capacity (PAWC) and non-limiting water range (NLWR) in a silty clay loam soil under rice-wheat cropping.

Lantana (Mg/ha)	SOC (%)	PAWC	NLWR
0	1.11	12.9	4.3
10	1.25	13.4	7.4
20	1.30	13.7	10.9
30	1.42	14.9	15.1
LSD (0.05)	2.0	1.1	1.0

Source: Sharma and Bhushan (2001)

3. *Use of mulches*

Mulching with organic or inorganic materials of natural (crop residues, waste plant biomass, wood chips, saw dust, coco-coir etc.) or synthetic origin (plastic sheets, soil conditioners), soil mulch or pebble mulch helps in conservation of soil mositure. Mulches, in addition to moisture conservation, help rainfed crops in several additional ways. In irrigated agriculture, mulching increase the effectiveness of irrigation by reducing evaporation loss of moisture from soil surface. Mulching keeps the soil moisture at a higher level for a longer time as compared to uncovered soil surface.

The choice of a mulch material depends upon its cost, availability, ease of handling and efficacy. The efficacy of mulching in soil moisture conservation depends on the kind, amount, method and timing of application of mulch. Mulch should be applied when the soil profile is almost saturated with water. In several field experiments, application of mulch in standing crop of maize, before the recede of monsoons, proved more effective in moisture conservation than when applied after maize harvest. When combined with zero tillage (i.e. conservation tillage), it produced more wheat yield than conventional tillage without moisture conservation under rainfed conditions (Table 5). Use of lantana mulch in wheat crop, not only conserved soil moisture and improved wheat yield, but also improved yield of maize crop by improving over-all soil health (Sharma and Acharya, 2000). Multilocation trials conducted at different locations on mulching of sugarcane crop revealed that trash mulching increased sugarcane yield significantly (Table 6).

Conservation tillage

Conventional tillage (repeated primary and secondary tillage operations) invariably enhances OM decomposition by breaking soil aggregates and exposing the soil to weathering agents, thus, weakening soil structure, and making soil loose to be washed away with runoff water. Conservation tillage (a non-inversion tillage that retains at least 30% of the soil surface covered by residues after planting, and is less intensive than conventional tillage) has been found as a potential alternative to conventional tillage to reduce soil erosion by water and improve and sustain soil health. The term "conservation tillage" is a broader classification for several crop production systems, including no-till, reduced-till, minimum-till, direct seeding and other names.

Conservation agriculture systems cover more than 70 million hectares worldwide, where these practices are used by small land holders. Conservation tillage produces crop yields the same as conventional tillage or even better (Table 5). If tillage operations are inevitable, they should be performed across the slope so as to retain water at soil surface and cut down the flow velocity of runoff water.

Table 5. Effect of mulch and tillage on wheat and maize yield under rainfed situations

Treatment	Wheat grain yield (Mg/ha)				Maize yield (Mg/ha)		
	1993-94	94-95	95-96	96-97	1994	1995	1996
LNT+CT	0.63	1.92	1.96	2.69	1.53	3.64	4.12
LNT+CC	0.67	1.71	1.64	2.60	1.63	3.69	4.45
LNT_{mh}+CT	0.55	1.31	-	-	1.70	3.33	-
CC	0.36	1.10	0.78	1.29	1.60	2.87	2.75
LSD (0.05)	0.18	0.20	0.22	0.17	ns	0.40	0.48

LNT: *Lantana* spp. mulch @ 20 Mg/ha (fresh biomass) applied in standing maize crop
LNT_{mh} : *Lantana* spp. mulch @ 20 Mg/ha (fresh biomass) applied after maize harvest
CT: Conservation tillage ; CC: Conventional tillage
Source: Sharma and Acharya (2000)

Table 6. Sugarcane yield as affected by trash mulching at different places in India

Treatment	Sugarcane yield (t/ha)		Soil type	Reference
	1988-89	1989-90		
Jalandhar, Punjab				
No mulch	32.6	35.8	sandy	Kanwar *et al., 1992*
Mulch	59.2	57.9	loam	
CD (0.05)	9.7	6.3		
Karnal, Haryana				
No mulch	48.5	47.2	sandy	Kumar and Srivastava, 1991
Mulch	64.2	57.2	loam	
CD (0.05)	12.6	13.3		
Muzaffarnagar, Uttar Pradesh				
No mulch	60.4	53.3	sandy	Malik *et al.*, 1996
Mulch	76.6	51.9	loam	
CD (0.05)	1.5	NS		
Sehore, Madhya Pradesh				
No mulch	70.6	55.8	clay	Sharma and Verma, 1996
Mulch	80.7	80.2	loam	
CD (0.05)	8.0	5.7		
Cuddalore, Tamil Nadu				
No mulch	102.0	127.9	clay	Pandian *et al.*, 1992
Mulch	116.4	135.5	loam	
CD (0.05)	14.3	7.0		

Source: Singh and Gupta (2009)

C. Crop Management

1. Use improved agronomic practices

Conserved/harvested rainwater is very precious and must be used very efficiently to cultivate high value crops, including vegetables, floriculture, nurseries, medicinal plants etc. The water should possibly be used through pressurized irrigation system. Its most efficient use can be achieved when combined with poly-house technology.

Farmers must follow improved agronomic practices to cultivate crops in order to sustain soil fertility, achieve maximum crop productivity and enhanced water use efficiency in rainfed areas. Some specific examples of agronomic practices that could bring about immediate positive results with regards to efficient water use in many rainfed are:

- Drought tolerant crops and crop cultivars having relatively short duration, deep root system and low water requirement
- Cultivate 'low volume high value crops'
- Improved crop calendars linked to seasonal precipitation probabilities
- Improved crop geometry and plant population
- Weed control (mechanical or chemical)
- Scientific use of chemical fertilizers based on soil test values
- Runoff reducing practices including contour planting
- Mechanical and vegetative bunding
- Maintenance of soil cover
- Water harvesting systems
- Use improved irrigation practices (drip and sprinklers) to recycle harvested water for crop production
- Make use of protective agriculture
- Improved fertility practices including legumes, and
- Improved forage livestock systems including forage legumes.

Proper fertilizer management plays an important role in increasing rainfed crop productivity. Nitrogen is the most important nutrient under rainfed conditions. Generally, NPK requirement of crops in relatively dry environments is lower than in high rainfall/irrigated areas. Fertilizer application to crops should be based on the profile moisture content and the rainfall pattern of the area.

2. Alley cropping

The alley cropping is an agro-forestry system in which food crops are grown in alleys formed by hedgerows of trees and shrubs. The hedge rows are cut back at planting and kept pruned during cropping to prevent shading and to reduce competition with food crops. When there are no food crops, the hedgerows are allowed to grow freely to cover the land. It can easily be adopted by resource-poor farmers and is ideally suited to marginal areas. Tree and shrubs in the alley system:

- Provide green manure or mulch for companion crops. In this way plant nutrients are recycled from deeper soil layers.
- Provide prunings, applied as mulch, and shade during the fallow to suppress weeds.
- Provide favourable conditions for soil macro- and micro-organisms
- Provide a barrier to control soil erosion when planted along the contours of sloping lands,
- Provide prunings for browse, staking material and fire wood.
- Provide biologically fixed N to the companion crop.

The major advantage of alley cropping is that the cropping and fallow phases can take place concurrently on the same land, thus allowing the farmer to crop for an extended period without returning the land to bush fallow.

The following areas may be taken up for experimentation in the rainfed farming development and thereby improving the total factor productivity of rainfed farming:

- Understanding and evolving suitable community organisation model
- Transfer of farmers best practices for wider use
- Identification and transfer of suitable technologies evolved by the research institutions
- Finding suitable extension processes and arrangements for the same
- Finding solutions to issues not addressed by best practices and modern technologies.

CONCLUSIONS

To improve productivity of rain fed areas there is a need to improve efficiency and profitable use of rainwater and other water resources in rainfed areas. Efforts should be made at reducing risks and shocks to the farmers so as to build their confidence in the rainwater harvesting technologies. Improvement in the management of rainwater has a vital role to play in the reduction of livelihood and enterprise risks caused by climatic uncertainties in rain fed areas.

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Review article

Watermoulds: Heterotrophs that Constitute Significant Part of Aquatic Ecosystem

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Aquatic fungi are usually microscopic organisms, which do not produce visible fruiting bodies but grow asexually as well as sexually. Their occurrence in water is rather subtle and specialised methods are needed to examine their diversity, population structure and ecological function. Aquatic fungi, being heterotrophs, are reliant upon photosynthetically produced organic matter. In the case of small particles such as algae, pollen, seeds and zooplankton carcasses, decomposition is achieved by the much smaller Oömycetes and Chytridiomycetes, rather than the aquatic Hyphomyctes. These fungi cause severe damage to larger aquatic organisms mainly fishes or fish eggs. This is of great importance for aquaculture since it necessitates antifungal treatments, but even in natural systems, watermoulds have the potential to severely harm the indigenous fish population. It has been shown that food web manipulations greatly alter the fungal biomass in lakes which suggests that saprophytic fungi transfer organic matter directly to the higher trophic levels of aquatic food webs. This distinctly indicates that watermoulds constitute an integral part of the aquatic ecosystem and aquatic food web.

INTRODUCTION

Hyde et al. (2007) have estimated that there are approximately 1.5 million fungal species on earth. Of these, only around 3000 species are known to be associated with aquatic habitats and only 465 species occur in marine waters (Shearer et al., 2007). This small proportion of aquatic fungal taxa is surprising because the aquatic environment is a potentially good habitat for many species. Aquatic fungi are usually microscopic organisms, which do not produce visible fruiting bodies but grow asexually (anamorphic fungi). Their occurrence in water is rather subtle and specialised methods are needed to examine their diversity, population structure and ecological function. Water associated fungi have been known historically as "phycomycetes", a functionally defined group consisting of "true fungi" (*Eumycota*) and "analogously evolved fungus-like organisms" belonging to *Chromista* (Oömycetes, Thraustochytridiomycetes). Other groups formerly placed in the fungal kingdom include slime moulds (Amoebae), Ichthyosporae (Mesomycetozoa) and Actinomycetes (Bacteria), which are now recognised as distinct taxa. While the "true fungi" are a sister group to animals, Oömycetes are biochemically distinct from fungi while having similar morphology, size and habitat usage (Money, 1998). Majority of these are saprobes or parasites (Czeczuga et al., 2004; Nechwatal et al., 2005).

Ecology of watermoulds and their role in aquatic ecosystems

Aquatic fungi, being heterotrophs, are reliant upon photosynthetically produced organic matter. In order of decreasing biodegradability, the fungal community consumes microscopic algae, macroscopic aquatic macrophytes and terrestrial plant litter (including wood). On localised spatial scales or short-term temporal scales, carbon and nutrients from other sources may gain high importance. Resources derived from animals include fish, fish eggs, carcasses, exuviae, living zooplankton, insects, feathers and hairs, while other plant-derived resources include pollen, spores, seeds and fruits (Cole et al., 1990). Interestingly, it seems to be nearly impossible to find a natural organic source that cannot be utilized by aquatic fungi (Sparrow, 1960). Aquatic habitats are heterogeneous in time and space and greatly differ in their physicochemical features. Consequently, composition and abundance of aquatic fungi should differ significantly between these habitats (Wurzbacher et al., 2010). Wurzbacher et al. (2010) have reviewed the ecology of fungi in lake ecosystems, and have presented a thorough discussion on fungal communities within the different water bodies. Similarly, Prabhuji (2011) has reviewed the interdependence of watermoulds occurring in water and soil habitats affecting their population density, distribution and periodicity. Watermoulds have also been shown to form part of terrestrial ecosystem in a transition from aquatic to soil habitat (Prabhuji, 2018).

Aquatic systems harbour a wealth of organisms that can serve as suitable hosts: algae from different phyla, cyanobacteria, protists, zooplankton, fish, birds, mussels, nematodes, crayfish, mites, insects, amphibians, mammals, plants and other fungi (Sparrow, 1960; Ellis and Ellis, 1985). Fungi are omnipresent and therefore, associated with almost every organism, often as parasites, sometimes as symbionts and of course as decomposers. Parallel to fungi in soil, aquatic fungi act as prominent decomposers of coarse particulate organic matter (CPOM) including plant and animal debris. Filamentous growth habit is a key feature of many aquatic fungi, and this feature is responsible for their superiority to heterotrophic bacteria as pioneer colonisers. Hyphae allow fungi to actively penetrate plant tissues and trap internal nutrients. Therefore, Gessner and Van Ryckegem (2003) have described fungal hyphae as self-extending digestive tracts that have been turned inside out growing hidden inside the substrate. In the case of small particles such as algae, pollen, seeds and zooplankton carcasses, decomposition is achieved by the much smaller Oömycetes and Chytridiomycetes, rather than the aquatic hyphomyctes. These organisms do not depend on macro-scale hyphal networks and are capable of very fast responses to changes in their environment. Their motile spores actively search for adequate substrates using chemotaxis. Once a suitable substrate has been reached, an appressorium is formed and the particle is invaded either endo- or ectophytically tapping the internal nutrient reservoirs for production of new spores in a sporangium (Sparrow, 1960; Sparrow, 1968). Their whole life cycle can thereby be completed in days. The short generation times and prolific spore production characterise these fungi as typical strategists. Watermoulds are often closely associated with insects, which can be key organisms in aquatic freshwater systems. Although often overlooked, these fungi represent a common and important component of almost every trophic level of any aquatic ecosystem.

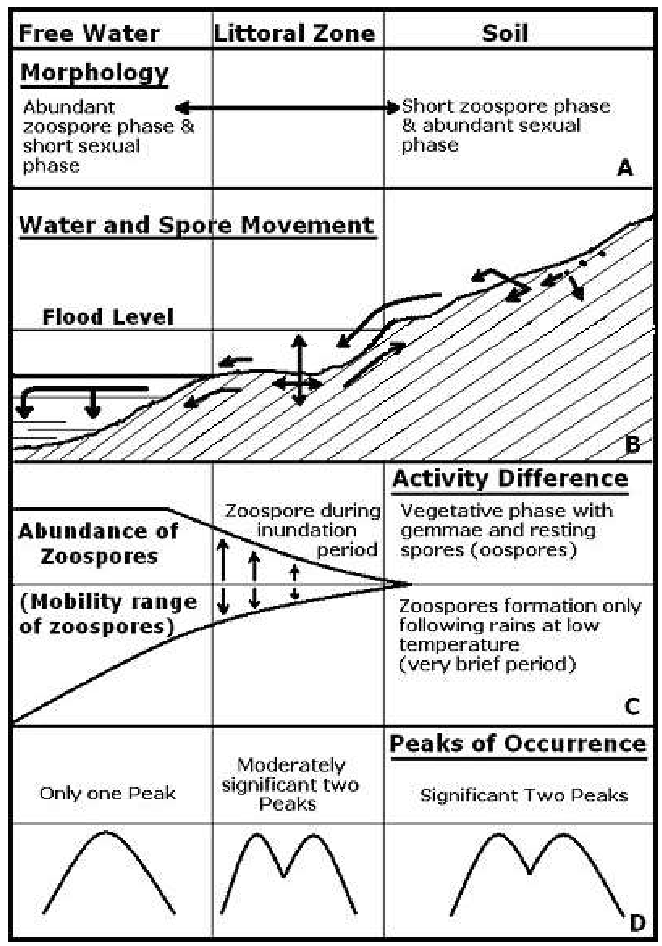
Many aquatic fungi are saprophytes, which consume dead organic matter (Dodds, 2002), but aquatic fungi may also be parasites or symbionts. In aquatic systems, the fungal community structure greatly differs between substrates (Shearer and Webster, 1985; Findlay et al., 1990; Bärlocher & Graça, 2002; Graça et al., 2002; Mille-Lindblom et al., 2006) and with the physico-chemical properties of the respective habitats, such as flow (Pattee & Chergui, 1995; Baldy et al., 2002), dissolved oxygen concentration (Field & Webster, 1983; Medeiros et al., 2009), nutrient concentrations (Gulis and Suberkropp, 2004; Rankovic, 2005), salinity (Hyde and Lee, 1995; Roache et al., 2006), temperature (Bärlocher et al., 2008) and depth (Wurzbacher et al., 2010). Therefore, fungal communities potentially differ between streams, shallow lakes and wetlands, deep lakes, and other habitats such as salt lakes and estuaries.

Roberts (1963) reported that watermoulds in aquatic ecosystems were distributed according to hydrogen ion concentration and arranged them in three groups: acid (pH 5.6 – 7.0), alkaline (7.0 – 8.8) and neutral (5.6 – 8.8). Lund (1934) and Srivastava (1967) also classified watermoulds based on water pH. Several other aquatic mycologists have also noted the significance of hydrogen ion concentration on the occurrence and distribution of watermoulds in water bodies (Ergaskev and Kirgizbaeva, 1978; Florinskaya, 1969; Hasija and Batra, 1978; Milanez, 1966; Suzuki and Nimura, 1960; and Zaborowska, 1965). However, pH may not be the only factor which determines the distribution of aquatic fungi. Roberts (1963) has pointed out that the watermoulds live on debris in the water and the type of decaying vegetation found in acid waters as opposed to that in alkaline waters may be the deciding feature in their distribution. In acid conditions, watermoulds may play a more important role in the decomposition of organic matter. Recently, Prabhuji (2014) has given an exhaustive account on pH mediated distribution of watermoulds in soil.

Stoll (1936), reporting on the occurrence and distribution of watermoulds with respect to temperature, stated that there were fewer species of these fungi in colder waters than in warmer ones. His conclusions supported the views of Lund (1934) that species of *Achlya* thrive best in cool temperatures and exhibit poor performance in warm waters. Ho (1975) has also recognized a correlation between water temperature and isolation frequency of watermoulds. Zeigler (1958) recorded temperatures extant at the time of sampling and found that these correlated with the oöspore type of the recovered species. Zeigler (1962) subsequently analysed the isolated species of watermoulds during his studies and indicated that the optimum temperature range for species with centric and sub-centric oöspores was 16 – 19 ºC, whereas that for eccentric oöspore forms was 19 – 30 ºC. Srivastava (1967) grouped watermoulds into 'low temperature species' and 'constant species', and most of the members were eccentric oöspore forms. Khulbe and Bhargava (1977) recognized four clusters of saprolegniaceous forms in the hilly lakes of India, viz., constant species in samples, collected at 10 – 28.5 ºC; low temperature species, most frequent in waters at 10 – 18 ºC; moderate temperature species, sampled at 18 – 22 ºC; and high temperature species, sampled at 24 – 28.5 ºC. Eccentric oöspore species were found more frequently in subtropical lakes and centric oöspore species in temperate lakes (Khulbe and Bharagava, 1977). However, Mer et al. (1980), studying the seasonal periodicity of watermoulds in lakes and soils of the same geographical and climatic area as Khulbe and Bharagava (1977), recognized only three groups: low temperature species (below 18 ºC); moderate temperature species (18.1 – 26.8 ºC) and constant species (8 – 26.8 ºC); and classified them into aquatic, amphibious and terrestrial (from soil samples) species. Furthermore, they reported that terrestrial forms showed two maxima, one in the spring and the other in the rainy season. They also observed that the centric oöspore forms were dominant in lakes, whereas eccentric forms dominated in soils. Maestres (1977) isolated several watermould species from Newfoundland and placed them into three categories: cold, warm, and intermediate temperature species. All the collected species had centric oospores: no species producing eccentric oöspores appeared in Maestres' collections (Maestres, 1977). Johnson et al. (2002) have suggested that it cannot be concluded from Maestres' report that eccentric oöspore forms are absent from cold water environments, and suggest that there is ample evidence from numerous collections that eccentric-egged forms occur in glacier-fed streams and other bodies of cold water in Iceland (Howard et al., 1970). Prabhuji (2005, 2011) has suggested that the centric and sub-centric oöspore forms dominate in temperate regions, and eccentric oöspore forms dominate in tropical regions of the globe.

The mineral content of water bodies has also been found to affect the watermould populations and to regulate their distribution significantly. Suzuki and Nimura (1961a) reported that out of a group of five lakes, three species of watermoulds – *Saprolegnia* sp. (unidentified), *Saprolegnia diclina* and *Aphanomyces* sp. (unidentified) – were found only in a lake having no detectable levels of iron, manganese, calcium, chloride or sulphate. Suzuki and Nimura (1962) analysed the watermould populations and hydro-chemical characteristics of a cluster of three lakes connected by a common watercourse that were rich in sulphate, chloride and calcium, but deficient in nitrate and phosphate. Each lake harboured the spores of water moulds but the species composition differed significantly among the three bodies of water.

Littoral zones are highly structured by large emerged macrophytes, floating macrophytes and submerged macrophytes, which can form a dense meadow and are suitable habitats for fungal proliferation. The high diversity of algae, pelagic and benthic species, and their function as an accumulation zone for dissolved nutrients and terrigenous detritus from the catchment, renders the littoral zone an ideal fungal habitat. Littoral sediments are often well aerated by the roots of emergent and submerged macrophytes and form microenvironments with strong physico-chemical gradients frequently altered by water movement and bioturbation by invertebrates such as mussels or chironomids. Therefore, it is not surprising that Willoughby (1961) found a high diversity and activity of fungi in soils on lake margins. Monchy et al. (2011) observed a high biodiversity in littoral water, and Mohamed and Martiny (2011) found a positive relation of fungal biodiversity to abundance of macrophytes. Fundamentally, aquatic habitats provide suitable conditions – with adequate moisture and optimal temperature – for watermoulds and, in turn, they produce evanescent propagules (zoospores) in luxuriance. In addition, because they are less likely to experience unfavourable conditions, watermoulds in aquatic habitats develop the least amount of resting propagules such as gemmae and oöspores. In contrast, the soil habitat, although it contains a good amount of organic matter, lacks adequate moisture and suitable temperature except during the rainy season, resulting in the development of a good amount of resting propagules (gemmae and oöspores) and fewer zoospores (Fig. 1A). During the rainy season, with adequate moisture and low temperature, the resting propagules in soils germinate and produce an abundance of zoospores, which are mobile within the water in soil pores; and are carried down the slope towards a stagnant or flowing water source. When soils are flooded or inundated, a similar phenomenon operates in terrestrial and the littoral zones, although for a short duration (Fig. 1 B, C).



Figs. 1. A-D: Occurrence and distribution of watermoulds in water bodies, littoral zones and in soils (Prabhuji, 2011)

Lawton and Brown (1993) introduced the concept of functional redundancy as a means of exploring the importance of biodiversity for ecosystem functioning. Functional redundancy is the idea that multiple species can perform the same function within an ecosystem, therefore, a reduction in number of species will not affect ecosystem functioning until all species performing a particular function are lost. However, functional redundancy is at odds with the concept of resource partitioning (Schoener, 1974), which proposes that competition between species drives them to specialise in exploiting discrete resources or ecological niches. Recent research has shown that biodiversity influences aquatic ecosystem processes such as productivity (Smith, 2007; Gustafsson and Boström, 2011) and heterotrophy (Cardinale et al., 2002), but studies of aquatic fungi show that diversity influences neither productivity (Baldy et al., 2002) nor decomposition rates (Bärlocher and Graça, 2002; Dang et al., 2005). It is likely that both functional redundancy and resource partitioning operate within aquatic ecosystems, but on different spatial and temporal scales, and with impacts at the level of individuals, populations and communities (Loreau, 2004).

Watermoulds as parasites

Prominent aquatic parasitic fungi belong to Chytridiomycota and Oömycetes. The host spectrum of these aquatic fungi is broad and covers every phylum including fungi itself (Sparrow, 1960; Van Donk and Bruning, 1992; Ibelings et al., 2004; Kagami et al., 2007). Encounters with fungi can be fatal to algae, particularly if their defence system is breached by the fungus. The ecological relevance of this negative interaction becomes evident when it is considered that suicide is a common defence mechanism in algae. If this controlled progress, called hypersensitivity, is initiated at the right moment during fungal infection, it results in the successful interruption of the fungal infection cycle, because the parasite's ability to reproduce via spore production is inhibited. Such "behaviour" allegorises a beneficial sanction since it protects the healthy algal population by reducing the abundance of the deadly parasite. However, if unsuccessful the parasite prevails and mass mortality of algae results. This can lead to shifts in the algal community composition.

These fungi cause severe damage to larger aquatic organisms. Some fungi, mainly oömycetes, infect fishes or fish eggs (Noga, 1993; Chukanhom and Hatai, 2004; Prabhuji and Sinha, 2010; Prabhuji et al., 2012; Prabhuji and Srivastava, 2013) and thereby exert strong population pressure. This is of great importance for aquaculture since it necessitates antifungal treatments, but even in natural systems, fungi have the potential to severely harm the indigenous fish population. *Aphanomyces astaci* (Oömycetales) causing the crayfish plague has driven the European crayfish (family Astacidea) population to the edge of extinction (Reynolds, 1988). In contrast, *Coelomomyces* (Blastocladiomycota) effectively infecting several mosquito species (Sparrow, 1960) has been discussed as a biological control for malaria mosquitoes (Whisler et al., 1975). The most infamous fungal parasite is *Batrachochytrium dendrobatidis* (Chytridiomycetales), which contributes to worldwide extinction of several known and unknown amphibian species (Berger et al., 1998; Skerratt et al., 2007). Aquatic plants are also greatly affected by fungal parasites. A recently discovered plant parasite watermould is *Pythium phragmites* (Oömycetales), obviously being an important causative agent of reed decline (Nechwatal et al., 2005).

Members of "Rozellida" have a similar life cycle as Chytridiomycetes, although diversity of *Rozella* has been so far only marginally described and is mainly based on the description of *Rozella allomycis*, a parasite living on *Allomyces arbuscula* (Prabhuji et al., 2010). It is known that these organisms probably have zoospores in the size range of 0.2 – 5.0 ìm, which are most abundant above lake sediments (Mangot et al., 2009). They are also found under reduced oxygen and anoxic conditions, (Slapeta et al., 2005; Luo et al., 2005). Sexual recombination can occur when two zoospores fuse together either in the free-swimming stage or on the host/substrate surface. Alternatively, resting spores might be formed in a pro-sporangium or in a zygote (Sparrow, 1960).

The members of Saprolegniaceae (Oömycota), like many others, are fundamentally facultative parasites that grow luxuriantly on decaying organic matter in aquatic ecosystem and, simultaneously parasitize aquatic fauna like fishes, amphibians and crustaceans and their eggs; and flora like algae and aquatic plants. Under unfavourable conditions, i.e., under water and temperature stressed situations they develop thick-walled oöspores following sexual reproduction to tide over adverse conditions of summer season having moisture as low as 5-10% and 30-35°C temperature and remain viable even in soil. Later, they produce abundant asexual spores (zoospores) on getting conducive conditions during monsoon and remain an indispensible part of the aquatic ecosystem as parasites on producers as well as consumers and as saprophytes constituting a part of decomposer-consortia. The seasonal occurrence of the members of Saprolegniaceae (Prabhuji, 1984a) may be visualized in the form of an ecological clock (Fig. 2).

The members of Pythiaceae have almost identical life cycle except for its mechanism of zoospore discharge and the tolerance limits of the oöspores. These oöspores may remain viable in almost dry soil and may tolerate 35-40°C temperature. Another virulent fish pathogen of chytridiomycetous life cycle is *Ichthyophonus hoferi* which is an obligate parasite and could not easily be cultured on media and therefore, its life cycle may only be studied on its host (Prabhuji and Sinha, 2009).

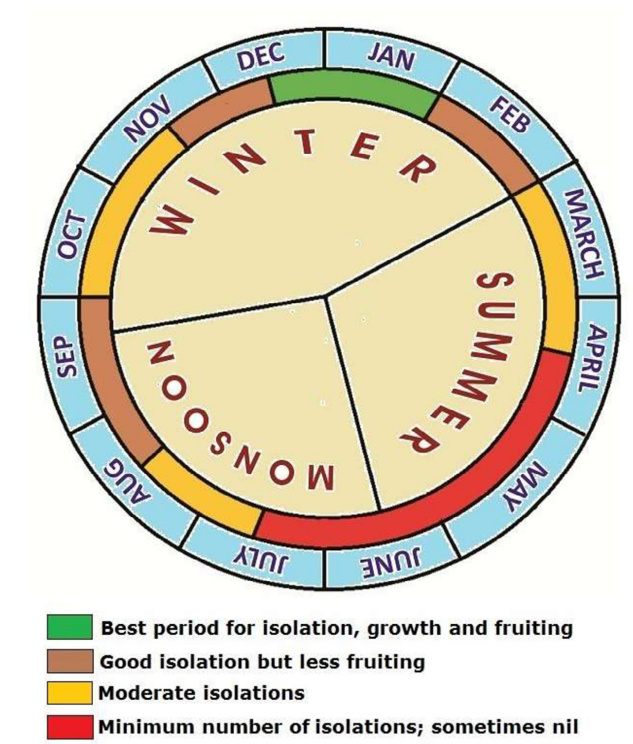


Fig. 2. Ecological Clock (after Prabhuji, 1984a)

Importance of fungi for aquatic food webs

The importance of fungi as secondary producers of biomass has been well described for headwater streams with leaf litter (Suberkropp, 1992) and for reed stands in littoral zones of lakes and in marshlands. The foregut content of 109 different aquatic insects collected on submerged wood showed that in 66% of all studied insect species fungi were part of their diet (Pereira et al., 1982) and many conidia of aquatic fungi were found in faeces of fish (Sridhar and Sudheep, 2011). Furthermore, it has been shown that food web manipulations greatly alter the fungal biomass in lakes (Mancinelli et al., 2002). This suggests that saprophytic fungi transfer organic matter directly to the higher trophic levels of aquatic food webs. It is therefore likely that environmental change can have severe consequences for overall food web topology, and hence nutrient and energy cycling. In addition, aquatic fungi can be important parasites of primary producers, e.g. phytoplankton, which fuel the aquatic food web with organic matter and energy. Lysis of aquatic organisms by fungal and protozoan parasites increases organic matter and energy cycling. These processes are often solely attributed to *Bacteria* and *Archaea*, however, aquatic fungi actively contribute as mineralisers and parasites.

CONCLUSIONS

Aquatic fungi are usually microscopic organisms and they occur in stagnant and flowing water and specialised methods are required to examine their diversity, population structure and ecological function. Being heterotrophs, they are reliant upon photosynthetically produced organic matter. These fungi cause severe damage to aquatic organisms mainly fishes or fish eggs as well as aquatic flora. This is of great importance for aquaculture since it necessitates antifungal treatments, but even in natural systems, watermoulds have the potential to severely harm the indigenous fish population. It has been shown that food web manipulations greatly alter the fungal biomass in lakes which suggests that saprophytic fungi transfer organic matter directly to the higher trophic levels of aquatic food webs.

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Review article

Beekeeping in Nagaland with Stingless Bees: Present and Future

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Key words
Rearing of bees, *Tetragonula iridipennis, Lepidotrigona* spp, Pollination, Hive products

Stingless bees are mostly found in tropical parts of the world. In India, these inhabit North Eastern states and South Indian Peninsula. About nine species of stingless bees are reported from India. Out of which five species are reported from Nagaland. These belong to Family Apidae with different genus. *Tetragonula iridipennis* is dominant followed by *Lepidotrigona* spp. Floral cycle of stingless bees disclosed important plants for different development seasons. Stingless bees nesting sites and architecture revealed different forms of cells comprising of queen, males and worker. Bees store honey and pollen in different cells which are bigger than brood cells. Rearing of bees is discussed with their utilization for pollination of crops. Different hive products are discussed with the constraints in stingless bee rearing.

INTRODUCTION

Honey bees are the best known and most useful insects, known not only for the production of honey and other valued hive products but also for their vital role as the dependable and most efficient pollinators of many crops and trees which lead to enhanced crop productivity besides contributing to the main tenance of ecological plant biodiversity. Beekeeping being a low cost, non land based enterprise can even be started by landless poor people and it is the most suited for integrated agriculture in North East India.

Pollination being an important component of the agro-ecosystem results in the increase in food security and improvement of livelihoods pollinators (McGregor, 1976; Free, 1993). North East India, comprises of eight states *viz.* Nagaland, Arunachal Pradesh, Assam, Meghalaya, Mizoram, Manipur, Sikkim and Tripura. These states have wide range of geographical and climatic conditions. Propagation of stingless bee colonies shall lead to preservation of biodiversity by conserving populations of bee species in the region. Among all the states, one thing is very common, the association of people with bees.

Agriculture is the main commercial activity and beekeeping is an important integral part of the people in the north eastern states since immemorial. Presently, in most parts of North Eastern states beekeeping is practised in traditional manner (in simple, tree trunks, logs, bamboos and underground domiciles) with low honey production and more bee colony loses.

Many states tried to rear different pollinators for better sustainability with the changing agriculture patterns (Saini et al., 2011; Chauhan, 2011; 2015). Stingless bees, *Apis cerana*, *A. florea*, *A. dorasta* are mainly explored in this region of country. *Apis mellifera* is tried in Assam and Nagaland. Recently, possibilities were explored and *Apis mellifera* was introduced in Nagaland for which the observations are still recorded to study their establishment success (Anonymous, 2019).

Nagaland is bestowed with large biodiversity of honey bee forage plants as well as bee fauna. All Indian species of honey bees are available in Nagaland along with stingless bees. *Apis cerana* and stingless bees are commonly seen in all the households of farmers, thus reflecting a never ending association of Naga people with bees. However, scientific beekeeping is not being followed in many parts of the state, though there is tremendous scope and capacity for expansion of beekeeping in Nagaland.

Nagaland among the biodiversity hotspots, has the potential of producing 15,000 metric tonnes of organic honey and 100 metric tonnes of wax annually from 3 million colonies thus providing a scope to generate Rs. 500 crores / annum. Among different honey bees, stingless bees and Indian honey bee are most dominant and farmer friendly bees found throughout the Nagaland, thus paving the way for the development of Meliponiculture and Apiculture as an important economy generator. Stingless bees are indispensable in the state because of their twin role in increasing crop productivity through pollination and honey production. Stingless bees are small bees belongs to order hymenoptera and class Apidae having 50 times more species than honey bees. It differs from *Apis* in many biologically significant ways. Meliponines cannot migrate. Also unlike honey bees, they produce brood in the manner of solitary bees, with mass provisioning. In general, stingless bees collects less honey but having high medicinal value and thus fetches very high prices (3-4 times more than *Apis cerana*) in the market. Stingless bee honey can be a gold pot for the beekeepers of Nagaland. Presently, Nagaland beekeepers trying to shifting towards scientific beekeeping for better and good quality honey harvest.

Stingless bees are promising pollinators of different crops for the following reasons: they are harmless to beekeepers and greenhouse workers, visit a wide range of crops (polylecty), are tolerant of high temperatures, are active throughout the year and can be transported easily, not susceptible to diseases and less enemies.

STINGLESS BEES

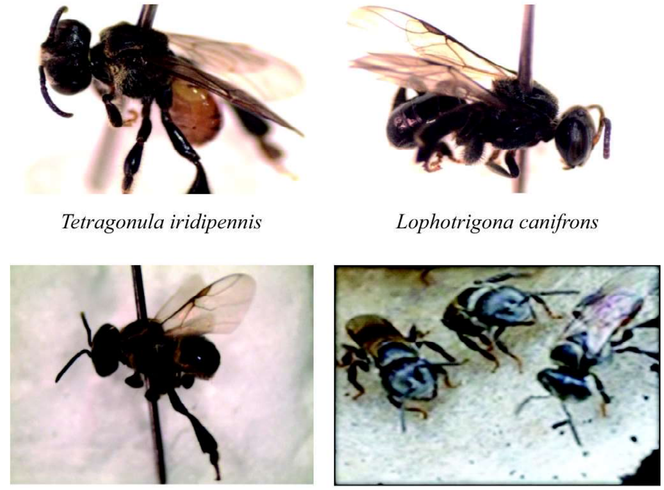
Stingless bees like other bees, are members of the class Insecta, order Hymenoptera and family Apidae, tribe Meliponini, sub tribe Meliponina and are closely related to common honey bees and bumble bees. Stingless bees are very important for their role in primary health care through production of medicinal hive products such as honey, propolis and bee bread. Like honey bees they live in cavities with a queen, workers (sterile females) and drones (males). Stingless bees are a large group of bees having about 500 described species found throughout the tropical and subtropical regions of the globe. Meliponines have stingers but has been significantly reduced and cannot be used for defence; hence, the term “stingless” is being used to designate the species. Some species have mandibles sufficiently strong to inflict a mild bite, pull hairs or may crawl into ears or nostrils of the intruders. Others emit a caustic liquid from the mouth that in contact with the skin causes intense irritation.

Stingless bee fauna of Nagaland

Nagaland is bestowed with huge flora and fauna biodiversity. Stingless bees are present in every pocket of Nagaland thus making this place a special stingless bee hub. Five species of stingless bees are reported from North East states in 2015 and out of these four species has been present in Nagaland only. Four different species viz., *Tetragonula iridipennis*, *Lophotrigona canifrons*, *Lepidotrigona ventralis, Lepidotrigona arcifera* and *Tetragonula laviceps* are identified in Nagaland province of India. Possibility of many more species (Figure 1) are there as it is one of the biodiversity hotspot (Chauhan and Singh, 2020).

Morphology of stingless bees

Stingless bees are very small in size. The colony consists of queen, workers and few drones. The external morphology of stingless bees is in three body parts: head, thorax and abdomen. Head bears antennae, compound and simple eyes and mandibles. Two pairs of wings and three pairs of legs are present on the thorax. The hind legs of have a modified structure, corbicula for pollen collection. The abdomen has non functional stingless apparatus. Most parts of the stingless bees are covered with hairs which poses them for pollination. These are yellowish brown to black in colour. Few species bear coloured bands on their abdomen. These bees nests in tree cavities and underground also. The natural nest architecture showed nest entrance oriented to south while some species make entrance to North West. The involucrum is made up of wax, cerumen mixed with mud. The brood cells are placed in the centre stacked over one another in horizontal manner. The size of queen cell ranges up to 7.15 mm length and 4.84 mm width while the worker and male cells are smaller in size (4.16 x 3.14mm and 4.06 x 3.09 mm). The honey pots (13.31 x 12.91 mm) and pollen pots (14.25 x 13.95 mm) are bigger in size than other cells present in the colony (Chauhan and Singh, 2019). These bees produce less honey i.e. 250 g/ nest.



Tetragonula iridipennis *Lophotrigona canifrons*

Lepidotrigona arcifera *Lepidotrigona ventralis*

Figure 1. Some species of Stingless Bees in Nagaland

Nesting sites of stingless bees

Many stingless bee species nest in cavities which can be found in stem and branches of living trees including bamboos, dead logs, old and abandoned ant hills, cracks in walls and wooden doors. The presence of nesting sites is essential for survival; maintenance and reproduction of stingless bees (Hubbell and Johnson, 1977; Eltz et al., 2003; Roubik, 2006). These bees use various natural materials for nest building which includes gums, resins and wax. Some also uses sand and mud with wax and propolis (Nogueira-Neto, 1997; Eltz et al., 2003; Roubik, 2006). The stingless bee colony consists of brood cells, honey and pollen pots. The brood is covered in many species while it’s open in others. The honey and pollen cells were connected with the brood cells through tunnels or sometimes are intermingled to the periphery of brood (Figure 2).

Figure 2. Long and Bamboo Hives of Stingles Bee

Life cycle of stingless bees

The stingless bee colony has division of labour and comprised of queen (only egg laying female), drones (males) and workers (sterile females). The queen mates with drone and get fertilized in flight. She lays two types of eggs. Fertilized eggs produce workers while unfertilized workers produce males. The queen is the mother of all the members of the colony and controls the day to day organization and activities of the nest. The workers are sterile females and do all the works of the nest except egg laying While drones only perform mating in stingless bees. Queen plays an important role in regulating cell construction and discharge of larval food by workers. In some species no egg laying by workers takes place even in the absence of queen (*L. ventralis*), where the cell construction ceased and the colony diminished day by day (Roopa et al., 2015).

Importance of stingless bees

Stingless bees are ecologically important species. They provide different high value hive products such as honey, wax, propolis and bee brood. The distinctive feature of this honey is that it is stored naturally in the pot (cerumen), thus contributing to its beneficial properties, especially in the wound healing process (Jalil et al., 2017). The composition of stingless bee honey differ from other species according to some physicochemical parameters (Ozbalci et al., 2013) and other studies prove that honey from stingless bees are more valuable and it has been used for a long time to treat various diseases (Souza et al., 2006). Propolis is hive product containing chiefly beeswax and resin derived from plant tissues or exudates (Bancova, 2009). On the other hand, cerumen is a mixture that is similar to propolis but with the addition of the mandibular secretion of the stingless bee during its construction (Santos et al., 2009; Simone and Spivak, 2010). Pollen is rich in proteins, vitamins and minerals and provides these nutrients to the bees (Ferreira and Absy, 2013). Pollen may be packaged and used as food supplements and also added to infant food. It is also used in many cosmetic preparations (Absy et al., 2018).

Besides these products, the stingless bees provide pollination services to different crops resulted in increased productivity and production of different crops (Figure 3). These also maintain the ecological biodiversity by rendering pollination services Roubik (1995).

Honey Wax Propolis/cerumen

Figure 3. Different Products of Stingless Bees

Flora of stingless beess

Stingless bees found to forage in flowers during all the seasons to collect pollen, nectar and resins. Besides pollen and nectar, stingless bee also collects resins from different plants. Floral calendar of stingless bees have been prepared for Nagaland under AICRP on Honey Bees and Pollinators, SASRD at Nagaland University (Figure 4). Total 82 plants were recorded on which stingless bees' forages for their sustenance. These include floricultural, vegetable, fruit medicinal and weed plants (Anonymous, 2019).

Rearing of stingless bees

Stingless bees are highly social bees found in the tropical and subtropical regions of the globe. These are known to be native of East Africa. In India, these bees are localized in North Eastern India, Southern and Western India including some states of central India. Among the seven sister states of India, these are found Nagaland and are reared in traditional manner. With advancement and interest of researchers, these bees are now reared artificial domiciles under natural conditions. Two methods are employed for stingless bee rearing: Traditional method and Scientific methods. In traditional methods, farmers use log hives. First a wild hive is located and then the branch or the trunk is cut around the hive. The log tree which has been cut is covered on both sides with a piece of wood and is sealed. While some people rear these in bamboo hives.

In scientific beekeeping, the brood (a small portion) is taken from the pre-existing hive and is transferred to brood chamber in scientific hives along with the queen. The scientific hive has separate brood and honey chambers. The daughter colony has been kept at same place where mother colony was kept so that the workers enters the daughter colony and starts raising the brood. Like this from a strong stingless bee mother colony 3-4 hives can be multiplied and in the next season, the daughter colonies also get strong and honey can be extracted from them.

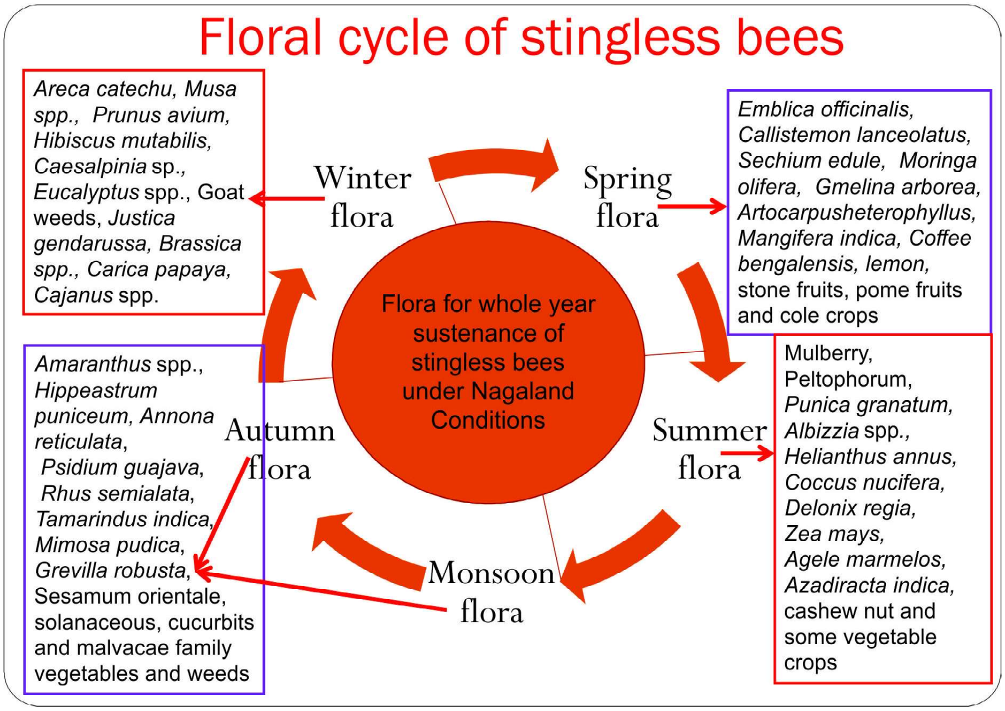


Figure 4. Stingless bee floral cycle in Nagaland

Stingless bees (Apidae, Meliponini) have received increasing attention as crop pollinators during the past few years. These highly eusocial bees live in perennial colonies, are easily domesticated and show various behavioural traits such as recruitment of foragers, high flower constancy, great diet-breadth, and easy adaptation to new plant species that make them promising candidates as pollinators of commercial crops (Roubik et al., 1986; Ramalho et al., 1994; Nogueira-Neto, 1997; Heard, 1999).

Scope of stingless bee rearing

In North East Region of India, most agri-ecosystems are organic thus increasing the scope of meliponiculture. Most of the farmers are keeping stingless bees in the traditional manner for honey extraction but still unaware of their pollination potential due to lack of studies in this field. Farmers grow seasonal vegetables and fruits but with changing scenario, the agriculture is getting intensified and is done under protected conditions. Under open conditions, natural pollinators are available but for pollination under protected conditions are still unexplored. With stingless bees as the native pollinator, opportunities are there to develop it into a commercial pollinator of different crops grown under protected conditions. Moreover, *Apis mellifera* which is used as a commercial pollinator in different parts of the globe is not present in Nagaland, thus providing a step in favour of stingless bees to be developed as commercial pollinator under NER regions of India. In litchi, cucumber and tomato, comparative pollination potential of honey bees and stingless bees are studied which disclosed the potential of stingless bees in these crops as the productivity was increased manifold as compared to without pollination.

Constraints in stingless bee rearing

The number of stingless bee colonies are increasing gradually, but the average production of honey from the colonies are not increasing because of old traditional practices and hives used by beekeepers. Some of the constraints hampering the development and growth of stingless bee culture are:

- Stingless bee diversity is still not fully explored.
- Unavailability of scientific techniques in stingless bee rearing.
- Lack of infrastructure and unavailability of superior domiciles.
- Technical knowhow for colony management to increase honey production.
- Lack of awareness to increase the crop productivity through managed pollination.
- R&D efforts in research for pest management.
- Loss of natural fauna supporting bee population.
- Consumer awareness of benefits of honey and other honeybee products for nutrition and health.

CONCLUSIONS

Stingless bees are important bees having great diversity in India. *Tetragonula iridipennis* and *Lepidotrigona ventralis* are abundant in Nagaland while *Lophotrigona* is present in low lands of the state. The different plants were identified for the seasonal management of stingless bees. The spring flora is available for build up of the colonies, summer flora helps in sustaining the colonies during dearth periods while the autumn flora helps in brooding and multiplication of colonies. The floral calendar provided a list of plants, the beekeepers should grow for scientific stingless bee keeping. Different hive products viz., honey, wax and cerumen can improve the livelihood of the farmers while the pollination services provided by bees will help in increasing the production and productivity of the crops.

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Mini Review

Quantification of Direct and Indirect Recreation Benefits of Melghat Forests

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Key words
Eco-tourism, Travel cost, Consumer's surplus, Benefit transfer

The present study attempts to compare recreation benefits by direct and indirect methods. The number of tourist inflow was found increasing over the period of time. After analyzing tourist trend over the years in Melghat, it was reported that number of tourists is increasing over the years. The direct revenue as per departments record was Rs.1.23 crores through various sources like tourists and vehicle entry fee, camera/video charges, safari, accommodation etc. But value of eco-tourism benefit by Travel Cost Method- TCM with benefit transfer was found Rs. 30.94 crores, which was higher than direct method. The recreation value has scope to improve through management interventions.

INTRODUCTION

Historically, *Melghat* is part of Berar region, which was rich in natural resources since prehistoric era. Berar earlier was an entry point of Aryans to south India. Though the origin of name *Varhad* is difficult to trace, a myth is famous that a large kinfolk of Lord Krishna who had accompanied him during his marriage, later settled here calling the region *Varhad* (Berar). Thus Berar region is witness of saga of lord Krishna and Rukmini. Amba temple in Amravati was the place where lord Krishna and Rukmini met for marriage. *Varhad* is now West part of Vidarbha. (Madhavrao, 1968). The historical importance apart from forest dominated hilly location makes Melghat landscape important from recreation point of view. The figure 1 indicates dense forest landscape and figure 2 indicate magnificent Bhimkund (kichakdara) falls where it is believed that the mighty Bhima of epic Mahabharat took bath after killing kichaka.

Figure 1. View of Melghat Forest landscape

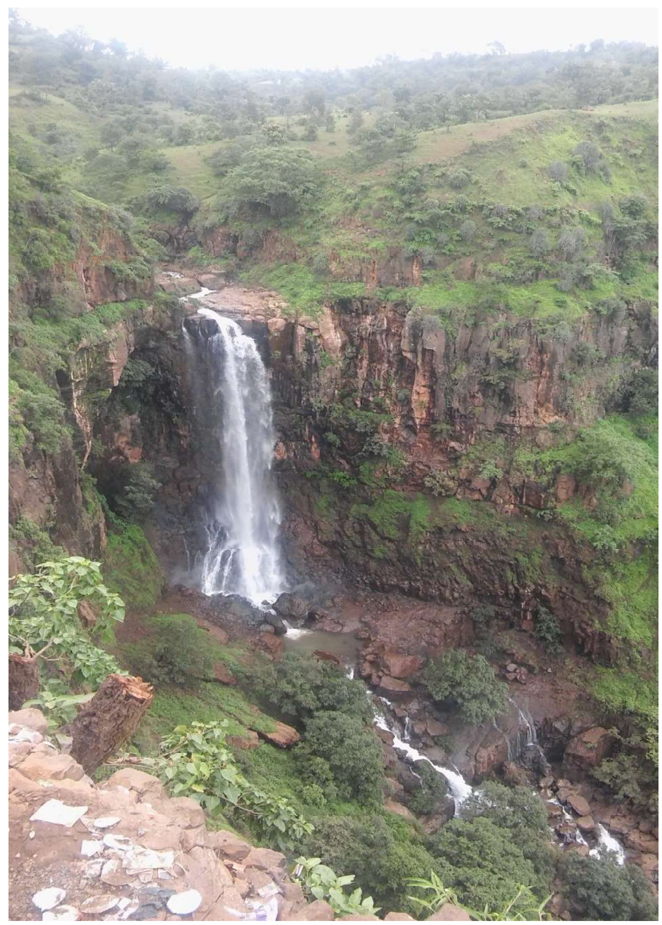

Figure 2. View of Bhimkund waterfalls in Melghat

Verma and Kumar (2006) in their report submitted to Central Statistical Organisation have elaborated valuation of recreational benefits of Pench Tiger Resrve, Madhya Pradesh.

The individual travel cost method (ITCM) was used for estimation of consumer's surplus of the visitors and economic worth of recreation in the Pench Tiger Reserve. The observation based on 24 onsite questionnaires used on weekends of April 2005. It was illustrated by them that, the ITCM though complicated method gives more prescise results. The results were quite helpful to planners and managers, as the ecotourism income was merely 1.29 millions against consumer's surplus was Rs. 50.71 millions. It has also been impressed by them that such study will enable a shift in direction of eco-tourism.

Gopal et al. (2016) have done economic valuation of tiger reserves in India, which uses a value plus approach. This study attempted to provide qualitative and quantitative estimates of ecosystem services of Crorbett, Kanha, Periyar, Ranthambore and Sunderban Tiger Reserves. Various 25 ecosystem services have been identified by the IIFM team which includes recreation benefits too. The concept of ecosystem services is elaborated with current context including time value of money, profitability indicators, market value approaches, benefit transfer etc. The services have a category as cultural services including physical and intellectual interactions with landscapes as well as spiritual, symbolic and other interactions. Quantification of ecotourism benefits was also part of study made by Shaikh et al. (2019).

MATERIALS AND METHODS

Study was conducted in entire Melghat forest landscape which represent Satpuda forest located in Amravati District of Maharashtra at the northern extreme of district. The Melghat landscape includes Melghat Territorial Division and MTR (Melghat Tiger Reserve). The part of Melghat area was declared as tiger reserve in 1974. Presently, the total area of the reserve is around 1815 sq km under management of Wildlife wing. The total area of Melghat including territorial forests area is 2969 sq km The Melghat landscape is a catchment area for five major rivers: the Khandu, Khapra, Sipna, Gadga and Dolar, all of which are tributaries of the river Tapti (Joshi, 1974).

The individual travel cost method (ITCM) following Verma and Kumar (2006) was used for estimation of consumer surplus of the visitors and the economic worth of recreation in the Pench Tiger Reserve (PTR). The final set of usable responses consisted of 24 onsite questionnaires that were administered on the weekends during April 2005. The individual travel cost uses survey data from individual visitors in the statistical analysis. This method thus requires more data collection and slightly more complicated analysis, but gives more precise results.

Benefit transfer comprises methods that rely on the use of research results from preexisting primary studies at one or more sites or policy contexts (often called study sites) to predict welfare estimates or related information for other, typically unstudied sites or policy contexts (often called policy sites). In a recent FAO manual for ecosystem valuation (Masiero et al., 2019), it has been recommended that the results obtained in study site A with similar profile are equally applicable to study site B. The study conducted in Pench Tiger Reserve is equally applicable to MTR. The comparative analysis is made from both based on direct valuation as well as benefit transfer approach whichever higher value shall be taken towards valuation.

RESULTS AND DISCUSSION

With rise in income level, the trend to explore new destinations is increasing day by day in India. People are willing to travel, spend money, relax on holidays and spend quality time with nature. The willingness to pay has brought boom in eco-tourism business. Eco-tourism by definition is the responsible trail in the nature without disturbing the essence of nature and helping in economic well being of forest dependent people. Melghat is not exception to this. As per office records available, there is increase in number of tourists over the years. As per available record, number of tourists visited Melghat in 2013-14 were 33882, which steadily increased to 55985 in 2018-19. The pattern of tourists visited during last 6 years in Melghat Tiger Reserve is shown in Figure 3.

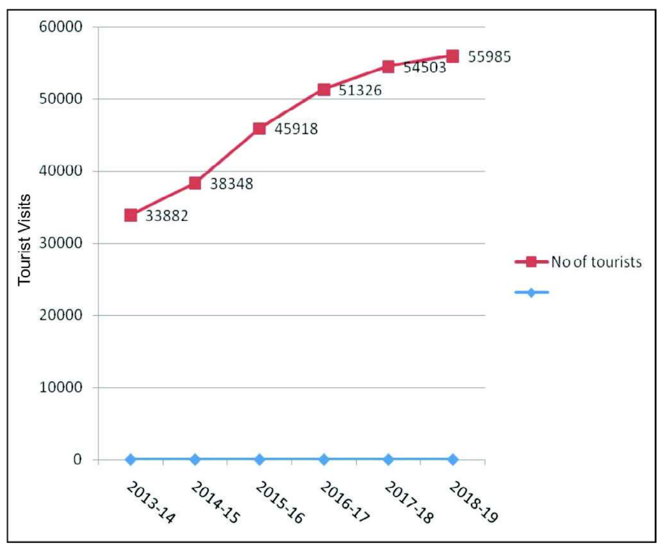

Figure 3. Pattern of tourist visits in Melghat Tiger Reserve between 2013-14 to 2018-19

Revenue is earned by department by imposing tourist entry fees, vehicle entry fees, camera charges as well as video shooting fees etc. Apart from this safari jeeps are made available to tourists at reasonable fees and optional accommodation in tourists camps are also made available.

Table 1. Annual Eco-tourism benefits of Melghat Tiger Reserve

Source	Revenue earned in Rs.	Remarks
Tourists entry fee	1675511	Collected on entry gates as well as online
Vehicles entry fee	3449614	From 26479 vehicles
Camera/ video	3624768	Professional use only charged
Sub-Total	8749839	
Safari and Accommodation	3588842	Revenue shared with safari jeep operators. Tourists guides earnings not included.
Total revenue	12338681	i.e. 1.23 crores direct revenue
Compared		Revenue by TCM is 30.94 crore rupees.

The revenue earned from all these sources is given in Table 1.

The expenditure done by tourists is much higher than the official revenue records. The travel cost includes hiring of vehicles, hotel expenses etc. The economic tool which takes into account consumer's surplus is called Travel Cost Method (TCM) which includes quantification of willingness to pay for a particular tour. The TCM method could be improved by adding weightage to foreign tourists visits through stratified sampling as this has potential to increase travel costs and willingness. A recent visit of the great cricketer Brian Lara to Tadoba Tiger Reserve (TTR) is one of the best examples that people including celebrities are keen to visit National Parks to sight a single tiger roaming wild. TTR and Tipeshwar Wildlife areas have comparatively better sighting value due to open meadows. MTR is mainly hidden tiger reserve with comparatively less sightings. The management intervention to improve sighting without disturbing delicate landscape balance is recommended for MTR. Even presence of tigers in huge numbers irrespective of sighting has its own wilderness and existence value, which definitely appreciable as unique management of MTR.

TCM method is known as revealed preference method as it utilised real consumer behaviour and preferences to derive a result. The willingness to pay to travel a particular site is used to work out a demand curve. The study was conducted at PTR with 24 on-site questionnaires in order to know number of trips, expenditure on trip, household income, and reason for travel, education level and age. The consumer's surplus was derived based on mean number of trips and curve of demand function. Consumers surplus worked out for PTR visitors was 2437.45 and recreation benefit was 507.10 laks.

FAO training manual by Maseiro *et al.* (2019) envisaged utility of benefit transfer approach (BTA) to quantify recreation benefits of study site based on TCM value of consumer's surplus worked out for a site with similar profile. Here PTR and MTR are similar sites from eco-tourism point of view. The consumers surplus value is taken as 2437.45 lakhs from PTR and applied to MTR with BTA method. While applying value NPV (Net Present Value) is taken into account as PTR value is of 2006 year.

Hence,

MTR consumers surplus= NPV of PTR surplus = 5527

Input variable changed as number of tourists visited in PTR were 20805 and for MTR 55985 visitors.

Recreation benefit in MTR= Consumers Surplus x number of tourists

= 5527 x 55985

= 30,94,29,095 i,e, 30.94 crores.

The recreation benefits still do not cover the employment generation in local communities through eco-tourism, which need separate elaborated study through socio-economic surveys.

CONCLUSION

Thus, after analyzing tourist trend over the years in Melghat, it is observed that number of tourists is increasing over the years. The direct revenue as per departments record was Rs.1.23 crores through various sources like tourists and vehicle entry fee, camera/video charges, safari, accommodation etc. But value of TCM with benefit transfer was found 30.94 which were higher than direct method. The recreation value has scope to improve through management interventions. Recent rise in tiger population is also going to increase tourism revenue in near future. The recreation benefits in Melghat landscape can be improved by improving sighting through management interventions, as sighting is major component of tourist inflow as well as good weightage in travel cost method.

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Mini Review

Opportunities in Tea Industry

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Key words
Tea industry, Prospects, Cultivation mechanization, Diversification

The paper deals briefly with the various aspects of the tea cup that cheers and cures. Tea is the most popular beverage in the world which is consumed widely next to water. Tea industry is one of the largest foreign exchange earner as well as a high employment generator. Tea cultivation is highly ecofriendly. It could be a large revenue earning business as its prices vary from Rs. 100 to Rs. 2 lakh per kg or more in the world market. It holds tremendous opportunities for R & D interventions in the areas of field and factory operations, mechanization in the field, start- up projects in product diversification and marketing of tea. Being an old plant based industry; its modernization will go a long way in overall improvement of the economy.

ORIGIN AND HISTORY

Tea is native of South-East Asia. It was known to Chinese as early as 2737 BC. Tea became a popular drink in England in 1664. In North India, tea experimentation was started by Robert Kyd at Kolkata in 1780. Robert Bruce is credited to discover tea in Assam in 1823. Its commercial cultivation began by 1838 in Assam. First shipment of tea was sent to London in 1839 and was sold in auction in London in the same year. In South India, tea cultivation began during 1859 -1879. Historically, over 60% of the world tea area have received planting materials from India, primarily before 1950 (Arya 2013; Asopa, 2007).

INDIAN TEA INDUSTRY

Tea is grown in India in over 6.0 lakh hectares which is the 2nd largest area in the world after China with over 10 lakh hectares. India is the 2nd largest producer of tea (1322 million Kg) annually after China (2609 million kg) and 3rd largest exporter (252 million Kg) annually, after China and Kenya. Globally, production share of India is 23% and of export 14%. Tea is one of the major export earning commodity in India amounting to over US $ 786 millon (Rs. 5056 crores). Major exports are to Egypt, Iran, Pakistan, China, Russia, U.A.E., Poland and Saudi Arab. We are the largest (90%) producer of C.T.C. (Crush, Tear and Cut) tea in the world (~ 900 million Kg).Tea industry in India is one of the largest employer of labour force (over 11 lakhs) which comes out to over 2.4 workers per hectare. Tea cultivation is highly eco-friendly (Asopa, 2007; Sivanesan, 2013).

PHARMACOLOGICAL INFORMATION

Black tea is rich in caffeine, polyphenols, vitamins, fluorides, tea pigments and tannins.

Green tea is useful in treating several ailments like abdominal, intestinal, cerebral, hemorrhages, nephritis, chronics, hepatitis, hypertension, cholesterol reduction, heart diseases, stones in urinary tract, gall bladder, liver and kidneys.

Tea has 40% less caffeine than coffee (brewed). It is further less (about 50%) in instant tea (mg/100gm). The beneficial effect of tea to health is widely accepted as could be seen in the Table 1 where its per capita consumption in many countries is listed.

Table 1. Tea consumption per head per year

Country	Quantity, Kg.
Irish Republic	3.21
United Kingdom	2.60
Kuwait	2.14
Turkey	2.08
Qatar	1.94
Syria	1.67
Sri Lanka	1.27
India	0.63

Among the major tea drinking countries, India is the lowest consumer of tea per head (0.63).

PROJECTION FOR 2025

Considering the ever increasing demand for tea annually, both domestically as well as externally, following projections have been made by the tea Board of India for Indian tea industry to achieve the target by 2025.

Production :	1506 million Kg
Productivity:	2889 Kg/ha.
Domestic consumption:	1588 million Kg
Export:	204 million Kg

INDIAN TEA SECTORS

The production and processing of tea in India are being done by corporate, private, state and small grower sectors.

Sector	% of total
Corporate	30
Private	24
State	1
Small tea growers (over 3 lakhs in nunmer)	45
Total	100

TYPES OF TEA (CATEGORIES) PRODUCED IN INDIA

There are three species of tea which are cultivated commercially to produce tea, namely Assam Type (*Camellia assamica*), China Type (*Camellia sinensis*) and Cambod Type (*Camellia assamica* ssp. lasiocalyx). The green leaves of these species are processed differently to produce various types of tea and their proportionate annual production in the country are as follows:

Category of tea	% of total annual production
Black	
CTC	90
Orthodox	8
Green	1.5
Others (Instant, Oolong, Special tea etc.)	0.5
Total	100

MODES OF MARKETING

Tea industry has a well established system of marketing. It includes auction, private sale, forward contract and sale through brokers. Of these systems, bulk of the teas are sold through auction. Auction centers are located at Kolkata, Guwahati, Siliguri, Amritsar, Jalpaiguri, Kochi, Coonoor and Coimbatore. Out side India, some major auction centres are Colombo in Sri Lanka, London in U.K., Mombasa in Kenya and Dubai in the United Arab Emirates.

PRODUCER SECTOR

It is divided into several groups which are as follows:

i. Corporate: Large Company of couple Tea Estates
ii. Private: Large tea estates (One to few).
iii. Small Tea Growers: Over 10 lacs, having tea holdings of 10 ha. or below
iv. Bought leaf factories
v. Green leaf dealers- intermediaries between small tea growers and tea factories
vi. Brokers: intermediaries between tea producers of made tea and buyers of tea
vii. Registered tea exporters

The entire tea business from production to primary marketing is handled by the above groups. The packeteers and retailers depend on above sectors to get the goods for further marketing.

TEA MANUFACTURERS

There is a well nit system of manufacturers to handle the processing of green leaf which are as follows:

i. Corporate sector tea factories: process own as well as bought leaves.
ii. Private sector tea factories: process green leaf of their own produce as well as bought green leaves.
iii. Bought leaf tea factories: Mostly process bought leaves coming from small tea growers.
iv. State and Self-Help Group factories: In recent years such factories have also come up which are processing tea leaves into made tea.

GOVERENMENT INTERVENTIONS TO THE TEA VALUE CHAIN

The tea industry is governed by the Commerce Ministry, Government of India through the Tea Board of India. It is a regulatory authority for the overall development of the tea industry. Regulation of subsidies, promotions, quality control, licensing, export, research etc. are handled by the Tea Board. Its head quarter is at Kolkata. The R & D centers are as follows which are engaged in developing need based field and factory technologies and their dissemination to the users:

i. Tocklai Tea research Institute, Jorhat, Assam under Tea Research Association, (TRA), Kolkata.
ii. Tea Research Foundation, Valparai under United Planters Association of South India (UPASI), Coonoor, Coimbatore.
iii. Darjeeling Tea Research & Development Centre, Kurseong, Darjeeling under Tea Board India.
iv. CSIR Complex, Palampur, H.P.
v. Himachal Pradesh Agricultural University, Palampur, H.P.

PROBLEMS AND BOTTLENECKS

Tea plantations in India, especially in North East India, covering almost 80% of the total acreage and production, is quite old (Kumar et al., 2008). It is facing following problems towards its development for increasing productivity and quality of made tea:

i. Old plantations of over 50-60 years or more, needing uprooting and replanting.
ii. Monoculture farming system, especially planting of few clonal cultivars on large scale inviting a great risk of damage by pests and disease.
iii. High cost of production due to being highly labour intensive industry.
iv. The production of a large quantity of inferior quality teas due to small grower sector which emphasize on

plucking coarse leaves, primarily to get more quantity for sale to the bought leaf factories.

v. Problems of water logging and flooding, especially in Assam, producing over 50 % 0f the national production, due to rising of Brahmaputra river bed, as a result of siltation and deforestation.
vi. Heavy taxation of various kinds.
vii. Frequent disruption of work due to the activities of the labour unions.
viii. Shortage of work force due to migration and absentism.
ix. Low workers productivity.
x. Minimal mechanization in field operations resulting in high cost of production.
xi. Problems of labour scarcity and high labour wages.
xii. Banned of many agrochemicals, due to toxicity of their residues in the made tea, resulting in high cost of production.
xiii. Price depressions and low profitability due to high cost of production.
xiv. Delay in realization of sale proceeds.
xv. Financial crunch being faced by R & D institutions like TRA,UPASI, DTRD&C etc.

OPPORTUNITIES

Tea industry has tremendous opportunities in the areas of R & D interventions, mechanization, start-ups in product diversification and marketing start-ups (Samantaray and Ashutosh, 2012). All these will generate lot of employment and will help in improving the overall economy of the country. Some of the specifics in the areas of opportunities are listed below:

a. Area for R & D interventions in field operations of tea plantations
   i. Soil compaction due to frequent movement of labourers in the field.
   ii. Soil management for better root growth.
   iii. Protection of roots from use of agrochemicals.
   iv. Improving present harvest index (12 -14%) to produce higher soft biomass (Leaf production).
   v. Breaking of inter-flush as well as winter dormancy in North East India.
   vi. Plant exploration for collection of genetic diversity in North East India and South-East Asia, being the hot spots of tea gene pools, before they are lost for ever, due to ever increasing demand for land .
   vii. Use of remote sensing for drainage improvement, land use, studies on ground water, tea vacancies, water bodies etc.

b. for R & D in mechanization
   i. Development of user friendly tools like sickles, hoes, pruning knives, spades etc.
   ii. Development of tea canopy friendly sprayers.
   iii. Development of efficient plucking shears.
   iv. Development of user friendly and affordable plucking baskets, plucking and pruning machines.

c. Start-up projects in product diversification
   i. Conversion of pruning litters into paper-pulp.
   ii. Extraction of polyphenols from pruning litters.
   iii. Production of consumer goods from tea like tooth paste, face cream, toffee, candy, shampoo etc.
   iv. Use of tea polyphenols in consumer goods.
   v. Products from tea seed oil which is comparable to olive oil.
   vi. Use of tea seed oil cake as fish feed and other uses.
   vii. Use of tea refuse (waste -2%) for extraction of caffeine, polyphenol, pectin, tannins etc.
   viii. Production of instant tea, ready to drink soft drink and tea tablets.

d. Start-ups in marketing of tea
   i. Value addition in tea like cleaning, spicing, flavouring etc.
   ii. Production of cost-effective, moisture proof packing materials to increase shelf life of tea.
   iii. Dissemination of tea knowledge for betterment of society like tea as a health beverage, tea tourism, use and miss-use of agrochemicals and development of small scale tea industries.

Finally, it could be concluded that the tea industry in India holds lots of opportunities for young as well as other entrepreneurs to improve personal as well as national economy.

The challenges are many. Their solutions will take the tea industry to newer heights.

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Mini Review

Combine Harvester: Opportunities and Prospects as Resource Conservation Technology

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Conservation technologies (CT) are being practised in over 3 Mha area in South Asia. Laser leveller, zero-till seed drill, paddy drum seeder, bed planter, rice transplanter, rotavator, straw reaper, happy seeder, etc are being used as efficient farm machines under resource conservation technologies (RCT). Combine harvester which performs three unit farm operations in single pass has wide potential for its further utilization under RCT. The combine harvesters were introduced at the advent of Green Revolution in India and their numbers grew from 800 in 1971-1972 to over 40,000 at present. While performing unit operations, it leaves the field with anchored stubbles and loose straw in windrow over harvested crop which causes the inability of coservation agriculture machineries to operate in such field condition and *in-situ* straw managment. This can be solved with suitable engineering interventions. A double disc type furrow opener consumed less force as compared to single disc type and runner type furrow openers. It is also found that straw mulch condition increased 21.4 -26.7% force requirement. Based on small scale prototype of double-disc furrow opener with power tiller, a concept of add-on sowing attachment with straw distributor/SMS is planned which is more suitable option under RCT, as two other unit farm operations can be added with the combine harvester. This will help in increasing the farm profitability by reducing the cost of operations and more utilization of combine harvesters by making it more verstile farm equipment.

Key words
Combine harvester, Zero-till drill, Happy seeder, Resource conservation technology, Straw reaper

INTRODUCTION

The technologies which conserve resources and ensure their optimal utilization and input use-efficiency are termed as resource conservation technology (RCT). These can be suitably addressed through efficient farm machines such as laser leveller, zero-till seed drill, paddy drum seeder, bed planter, rice transplanter, rotavator, straw reaper, happy seeder etc. Recent estimates have revealed that conservation agriculture based resource conserving technologies (RCTs) are being practised over 3 Mha in South Asia. The present practice clearly indicates use of RCT for paddy and thereafter sowing wheat crops. A machine designed to efficiently harvest a variety of grain crops by combining three separate operations (reaping, threshing and winnowing) into a single process, called combine harvester is spared in RCT fold. This might be due to its use in only harvesting and leaving residue in windrow at site.

India has world's largest area under rice with 42.75 million ha and is the second largest producer (105 million tonnes - 2013) next only to China. It contributes 22.34 % of global rice production. The present harvesting practice in the country is either through manual and/ or mechanical harvesting. In mechanical harvesting, combine harvester is a common machine which poses problems of disposal of straw in the very short time available between the harvesting and the sowing of next crop (wheat/pulse). According to MNRE (2009), the amount of crop residues generated was 500 million tonnes (MT) and surplus was 141 MT. Out of 82 MT estimated surplus residues from the cereal crops, 44 MT is from rice alone followed by 24.5 MT from wheat. Farmers find it easier to opt for burning the residue in the open field compared to other residue management techniques to avoid delay of sowing of next crops. However, the issues of resource conservation alongwith reducing production costs, increasing profitability and making agriculture more competitive have assumed importance in view of widespread resource degradation. Thus, the surplus residues i.e., total residues generated minus residues used for various purposes, which are typically burnt on farm, should be managed in such a way to address the farmers' concern.

About 30% (11.7 m ha) of the area under rice production during *Kharif* (rainy) season in India remain fallow in the subsequent *Rabi* (winter) due to number of biotic, abiotic and socio-economic constraints. Despite of ample opportunities, rice-fallows system has been bypassed in the research and development in the past. Pulses on account of low input requirements, short duration, ability to establish with surface broadcast in standing rice fields and soil fertility restoration property are ideal for rice-fallows. Among the abiotic constraints soil and water are the two major limiting factors which lead to low productivity of pulses in rice-fallows. Rice-fallows system received considerable amount of rainfall during *Kharif* season. However, the amount of rainfall received during the *Rabi* (winter) season is low and erratic. Thus, growing of *Rabi* pulses solely depends upon the availability of soil moisture remained in the field after harvest of rice crop. The productivity and profitability of pulses introduced in rice-fallows can be improved with application of suitable crop management techniques for efficient utilization of residual soil moisture (Pratibha et al., 1996; Kar et al., 2004). Rice straw mulch can be an effective measure for reducing soil evaporation and improving soil water storage. Mulch in rice-fallows can also minimize weeds infestation and water loss by weeds through transpiration. Thus, it facilitates more retention of soil moisture and helps in control of temperature fluctuations and improves physical, chemical and biological properties of soil. FAO (2016) stressed the need to developing new machines and precise techniques that are more protective of the environment are the key to climate-smart agriculture. One powerful concept is conservation agriculture (CA) where a permanent cover is maintained on the soil and direct seeding is used through the vegetative cover. Direct seeding is only possible option to act as Climate-smart agriculture which may be a vital tool for building resilience against the extreme weather events that are expected to intensify as a result of climate change.

In this paper, an attempt is being made to study the adopted engineering solutions for RCT enabled CA and potential of add-on sowing machine with combine harvester as this machine is increasing its adoptability by the farmers at a fast pace in India due to labour shortage and associated economics.

Conservation machineries adopted under RCT

After harvest of paddy crop, following farm equipment is being operated under conservation agriculture for sowing of next crop,

Zero till drill creates a narrow slit for the seed and does not disturb or turn over the soil in the process of seeding the crop. This drill is mounted with rigid tines and inverted-T openers and works satisfactorily under anchored stubbles. It is observed that it gets clogged frequently under loose straw conditions. Other limitations with this drill is poor traction of the seed metering drive wheel due to the presence of loose straw, and the need for frequent lifting of the implement under heavy residue conditions. This has resulted in uneven seed depth and thus poor crop establishment. Therefore, research organizations have tried with double disc openers, triple disc openers either with powered or unpowered plain disc coulters as well as star wheel type planter in place of inverted T-type furrow opener of zero till drill. Its wider adoption in wheat was due to increased yields, reduced production costs, 13-33% less water for irrigation and saving of Rs. 2400-3000 per ha (Fowler and Rockstrom, 2001; Knowler et al., 2001; Malik et al., 2002; Gupta, 2003).

Another machine which is commonly used in RCT is Happy seeder which is a tractor-mounted machine that cuts and lifts rice straw, sows wheat into the bare soil, and deposits the straw over the sown area as mulch. This machine allows farmers to sow wheat immediately after harvest of rice crop without burning any rice residue for land preparation. This machine offers many benefits to the farmers which include reduced fuel consumption, cost of crop establishment and timeliness in sowing and reduced water for irrigation. Sidhu et al. (2015) reported in their study about low adoption of the machine despite a 50% price subsidy. Further they highlighted the constraints to adoption which include the low window of operation of the machine (25 days per year), the low machine capacity compared with conventional seed drills, the inability to operate in wet straw, and the lack of straw spreaders/ SMS on combine harvesters.

Combine harvesting in india

The combine harvesters were introduced at the advent of Green Revolution in India and their numbers grew from 800 in 1971-1972 to over 40,000 at present (Thakur, 2004 and Damodaran, 2016). These combines are manufactured by over forty eight manufacturers of Punjab and Haryana. Every year 900-1000 combines are added on Indian farms. Earlier the combines were used in Punjab, Haryana and Western Uttar Pradesh but at present, penetration of combine harvester is across the length and breadth of country due to consistent labour shortage, high wage rate during harvesting season and uncertainty of weather. The combines have become a source of income to many of the agro-industries and private entrepreneurs under custom-hiring mode. The combining intensity, defined as the ratio of total area of combine harvestable crops to the area actually harvested by combines is expressed on percentage basis. 50-60 per cent of the paddy in Punjab-Haryana and 70-80 per cent in the Cauveri and Krishna-Godavari delta regions of TN and AP is now combine-harvested. That ratio could be 85-90 per cent for wheat in Punjab and Haryana (Damodaran, 2016). The combine harvesters market in India is estimated at 4,000-5,000 units annually by sales which have grown at a CAGR of 28% since 2006. Amongst 48 manufacturers, leading manufacturers are CLAAS India Ltd., Preet Agro Industries Pvt Ltd, Balkar Combines, Vishal Combines, Standard Combines, Kartar Agro Industries Pvt Ltd, and Hira Agro Industries that have a strong presence in the combine harvester market in India (Mehta et.al. 2014). The population of combine harvesters in India is 0.04 million up to year 2016-17 and about 1% share in total farm power availability of 2.24 kW/ha (Mehta et al., 2019). Globally it can be seen from mechanization Table 1.

Table 1. Comparison of farm mechanization with other countries*

Country	Farm Power (kW/ha)	Number of tractors per 1000 ha	Number of Combine harvester/ 1000ha
India**	2.02	37	0.28
Japan	8.75	456.24	234.42
United Kingdom	2.5	88.46	8.32
France	2.65	68.52	4.93
Italy	3.01	201.90	6.24
Germany	2.35	87.26	11.43
Pakistan	-	14.92	0.074
Egypt	-	31.32	0.8311

**Mehta M M (2007) ** Damodaran (2016)*

Study on type of furrow opener for add-on sowing device

A study was conducted in year 2015-16 at ICAR-IARI, New Delhi in soil bin to assess force requirement in operation of furrow openers at bulk density of 1.32 g/cc (db) in soil bin. Three type of furrow openers namely runner type, single disc type and double disc type (Figure 1) were selected. An experimental set up was fabricated to mount the selected furrow openers for force assessment (Figure 2). The disc diameter was 335mm. The force was measured using 981N load cell under mulch and without mulch conditions. Depth and cross-sectional area of each furrow opener was measured.

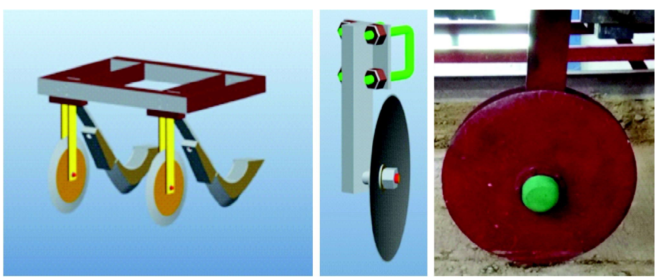

Figure 1. Selected furrow openers- Runner type, single disc and double disc type

Figure 2. Experimental setup for measurement of force in Soil bin.

Table 2. Performance of different type of furrow openers in soil bin

Type of furrow opener	Depth, mm		Draft, N		Cross-sectional area, mm2
	Without mulch	With mulch	Without mulch	With mulch	
Double disc	25	25	60	80	20
	50	50	75	95	50
Single disc	50	50	140	170	120
Runner type	25	-	160	-	100

Table 2 clearly indicated the low force requirement under mulch and without mulch condition with double disc type furrow opener than single disc type furrow opener and runner type furrow openers. It is also clear from table that force requirement was 21.4% higher under mulch condition with single disc type furrow opener followed by 26.7% higher with double disc type furrow opener. No trapping of straw was observed with double disc type furrow opener while there was some trapping was found with single disc. Runner type furrow opener could not be successful under mulch condition. The cross-sectional area was least with double disc furrow opener followed by runner type furrow opener and single disc type furrow opener under without mulch condition. This study suggested use of double disc type of furrow openers under straw (mulch) condition due to less force and furrow cross-section area.

A small prototype of 4 double disc type furrow openers was fabricated for field assessment. The double disc type furrow opener was mounted on power tiller (Figure 3). The field operation with this furrow opener needed more weight for its proper functioning with power tiller. A load of about 800N was added on the frame of this furrow opener. The performance of the double disc type furrow opener showed similar trend as observed in soil bin with slightly more furrow cross-section.

Figure 3. A small scale prototype of double disc furrow opener & its field operation.

DESIGN OF ADD-ON SOWING MACHINE WITH COMBINE HARVESTERS

As per the lab and field studies, a plan was further made for add-on sowing attachment with combine harvester. The findings and observations recorded with combine harvesting clearly indicates its increasing trend in adoption by the farmers since year 1972. Apart from ease to farmers in getting grain just after harvesting of cereal crops, it has posed some residue problems like cutting stalk height and left over residue in harvested field. Other points which might restrict owning of combine harvester by farmers are of only use as a single operation of combine harvesting though which includes harvesting, threshing and winnowing. Present day, conservation agriculture and resource conservation technology is prime area of concerns of agriculturist. Keeping in view of this an attempt is being made to utilise the combine harvester for other operation like sowing of next crop along with harvesting of preceding crops simultaneously, particularly after rice harvesting. The advantages for potential attachment of sowing machine with combine harvester are

- Utilisation of residual moisture of field for next crops due to very less time available for sowing of next crop.
- Reduced dependency on rain or irrigation water for germination of seed and hence avoid terminal drought condition.
- Energy saving for preparation of field.
- Providing option to avoid burning of straw that help in protecting environment.
- Reduction of soil compaction due to heavy traffic in field during subsequent operations.

The design considerations for sowing machine with straw spreader/ straw management system (SMS) for combine harvester is given below,

- Space available in combine harvester for attachment of sowing machine is either between rear and front wheel or between front wheel and cutter bar assembly. Also, there is scope to attach at mounting provided at rear axle of combine harvester by some manufacturers. However, the location between rear and front wheel will be better choice for mounting the attachment because it enables single axle mounting for almost all combine harvesters.
- The sowing attachment is to be mounted type.
- A single square axle may be provided for mounting of machine by hinging to main frame of combine harvester. The hinge movement will also accommodate the seeding depth requirement. The vertical movement of main axle will be controlled by hydraulic.
- The square shaft will also facilitate for easy row to row adjustment of furrow openers due to its mounting by U-clamp.
- It is observed during pre-trial that harvested stalks may tend to entangle furrow opener that might affect crop establishment.
- Amongst various types of furrow openers, double disk furrow opener may reduce the entanglement of stalk in seed placement at proper depth.
- The paddy stalks are having about 30-40% moisture content which might affect seeding depth even with double disk furrow opener. For proper seed depth with double disk furrow opener may be ensured by hydraulic load. Ahmad et al. (2015) have found the force requirement of 905, 1554 and 1620 N for penetration of double disc furrow opener of 300, 450 and 600 mm diameter, respectively in clay loam soil with straw density of 0.2 kg/ m^2 area.
- Since plan is to provide furrow opener at variable spacing due to different crop requirement, individual seed metering will ensure its proper distribution of seed in each row.
- Seed hopper may be kept for sowing of 0.6 ha area at a time. The grain tank capacity of a 4.3 m combine harvester is about 2.6 m^3. This grain tack capacity will be emptied after harvest of about 0.28ha area. So after 2nd time emptying the grain tank, seed hopper may be filled. Thus, a hopper capacity of 0.1m^3 will be sufficient. In the combine harvester with sowing attachment, two hopper of equal size (0.05m^3) may be provided at its both sides. Each hopper will have seed distribution mechanism for half of total furrow openers. Harvesting and sowing is proposed as simultaneous operations, hence, synchronization of seed metering with combine operational speed is required which can be met with a controller. Development of optical sensor based speed synchronization system may consist of optical encoder, DC motor drive, microcontroller; battery pack and chain drive with suitable programme to synchronize the speed of DC motor which drives the seed metering mechanism with the forward speed of combine harvester.
- In one ha area, paddy straw yield is about 15 tonnes/ha when it is ground cut. Combine harvesting is normally done at 30 cm height with forward speed of 0.83 m/s. So 1/3rd straw will be dropped in windrow of about 1m width in form of heap on anchored stubbles. This straw density may affect seed germination in that area sown with developed sowing attachment with combine harvester due to generation of more humus with temperature and its thickness. Therefore, straw dropping rate will be about 1.5 to 2 kg per m^2 harvested area.
- This dropped straw in heap needs to be spread in its full width of combine harvested area. Straw distribution can be made with chopped or without chopped straw. Chopping can be done by providing cutting mechanism along with spreader while combine harvester in

operation. Spreading can be done with spinning star wheels.

Based on the above-points and design considerations, a conceptual design of sowing attachment is shown below in Figure 4. The potential of add-on sowing attachment with spreader/ SMS can be estimated based on combine availability and its per annum manufacturing. This proposed system with combine harvester would provide immense benefit to the farmers for increasing their profitability, combine manufacturers and agriculturist in saving environment which may prove to be a climate resilient technology.

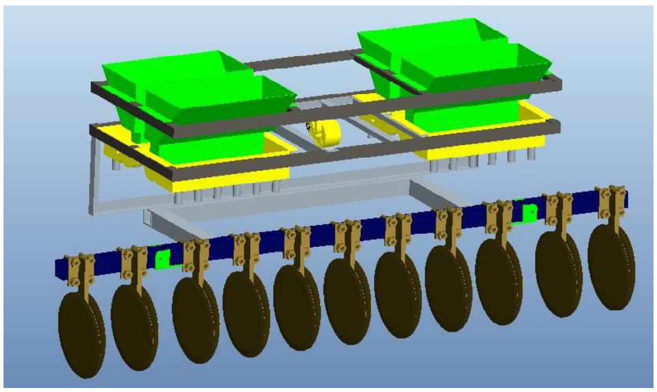

Figure 4. Conceptual plan of Sowing attachment with combine harvester.

CONCLUSION

Combine harvester has numerous advantages in the current scenario of labour shortage, high wage rate during harvesting season and uncertainty of weather and has wide potential for its further utilization under resource conservation technology. The add-on sowing attachment with combine harvester would help in timeliness of sowing of Rabi season crops apart from utilization of residual moisture and reducing the number of passes of heavy prime movers in the field, hence reducing compaction. Double disc type furrow opener was found best among selected furrow openers under straw mulch condition in the soil bin study. The force requirement with this type of furrow opener was also lowest among others. This type of add-on sowing attachment having double disc furrow openers will further enhance the value to combine harvester as versatile resource conservation technology.

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Research Article

A Primer on Entomopathogenic Nematodes for Biological Management of Insect-pest of Crops

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Key words
Entomopathogenic nematodes, Insect biocontrol, Mutualism, Symbiont bacteria, Field application, Insect-parasitic nematodes

Entomopathogenic nematodes are a special category of nematodes that can kill an insect within 72 hours along with their symbiont bacterial populations. These nematodes naturally maintain a symbiotic relation with specific enteric bacteria. Because of their high pathogenicity and reproductive potential, entomopathogenic nematodes are used worldwide for biological management of various insect-pests of agricultural crops. This article provides a brief introduction to entomopathogenic nematodes, and discusses important aspects of their biology, mass production, use in agricultural pest management, and its brief history in India.

INTRODUCTION

Nematodes or roundworms are one of the most abundant metazoans on the Earth. They are found in almost all conceivable habitats and could be free-living, animal- or plant-parasitic. Several nematode families are insect-parasitic, and within these insect-parasitic nematodes, the nematodes belonging to families Steinernematidae and Heterorhabditidae are commonly termed as entomopathogenic nematodes (EPNs) because they employ bacteria to kill the insect host very quickly. Recently, few species from Rhabditid genus *Oscheius* has been included under the category of EPNs. Classically, the hallmarks of entomopathogenic nematodes have been: 1) carriage of pathogenic bacteria by infective juvenile (IJ) nematodes (also known as dauer juveniles); 2) active host-seeking and -penetration by IJs; 3) release of the bacteria into the insect hemolymph; 4) death of the insect, and nematode reproduction and bacterial proliferation driven by cadaver-nutrient utilization; 5) re-association of the pathogenic bacteria with new generations of IJs; and 6) emergence of IJs from the nutrient-depleted cadaver as they search for new insect hosts. To differentiate EPNs from other forms of insect parasitic nematodes, Dillman et al., (2012) proposed two criteria based on the fundamental principles of the EPN lifestyle. These criteria are 1) the nematodes use a symbiotic relationship with bacteria to facilitate pathogenesis, which implies that the association is non-transient, though not necessarily obligate, and 2) insect death is sufficiently rapid that it can be unequivocally distinguished from phoretic, necromenic, and other parasitic associations (i.e. < 120 h). This time frame also implies the efficient release of the pathogen by the nematode vector.

These nematodes have very high potential as bio-agent against the insect pests, due to following attributes – i) Like parasitoids/predators, they have chemoreceptors and are motile; ii) like pathogens, they are highly virulent, killing their host within 24 to 48 h.; iii) can be cultured easily *in vitro*; iv) have high reproductive potential; v) have broad host range; safe to the plant and animal health, and the environment; vi) can be easily applied using standard spray equipment; vii) have potential to recycle in the environment; compatible with many chemical pesticides. Till date, there are two genera listed under Steinernematidae – *Steinernema* and *Neosteinernema,* with more than 100 species in the former and only one species in the later. Under Heterorhabditidae, there is only one genus – *Heterorhabditis* with only 21 known species (Bhat et al., 2020). These nematodes maintain highly specific symbiotic relationship with the members of Gram-negative Gammaproteobacteria. The *Xenorhabdus* (Thomas and Poinar, 1979) and *Photorhabdus* (Boemare et al., 1993) are Gram negative, anaerobic rods, classified under the family Enterobacteraceae. *Xenorhabdus* spp. are associated with *Steinernema* while *Photorhabdus* spp. are associated with *Heterorhabditis*. The *Oscheius* nematodes are associated with insect-pathogenic bacteria of the genus *Serratia* (Abebe et al., 2011).

The life cycle of Steinernematids and Heterorhabditids

The infective juveniles (IJs) carry bacteria in their digestive tract and penetrate the insect host through natural openings in case of Steinernematids and also direct penetration through integument in case of Heterorhabditids. Nematodes reach the haemocoel where the bacteria are released. The bacteria multiply rapidly and cause septicaemia, thus killing the host within 24 – 48 h. The nematodes feed on the bacteria and host tissue, complete 2 to 3 generations, and emerge from the cadaver as IJs within 7 –10 days in case of Steinernematids, and 12 to 15 days in case of Heterorhabditids. The emerged IJs are ready to infect the new hosts. The nematode-killed insects are flaccid and do not have a putrid odour because the mutualistic bacteria produce antibiotics which prevent the growth of secondary microorganisms. Insects killed by Steinernematids turn yellow-brown, pale or black whereas those killed by Heterorhabditids turn red, brick-red, purple, orange or sometimes green. In the dark, the Heterorhabditid-infected insects will luminesce due to the presence of *Photorhabdus* bacteria, and the internal tissues are gummy or sticky.

The nematode and the bacterium are an excellent example of animal – microbe mutualism. The nematode is dependent on the bacterium for i) killing its host; ii) creating a suitable environment for nematode development and preventing the infection by secondary microorganisms; iii) serving as a food source; iv) breaking down the host tissues to serve as a nutrient source for the nematode. The bacterium needs the nematode for i) protection from the external environment; ii) penetration into the host's haemocoel; iii) inhibition of the host's antibacterial proteins.

Mass-production of entomopathogenic nematodes

Most Steinernematids and Heterorhabditids can easily be cultured *in vivo* on wax moth larvae (*Galleria mellonella*) or any other bait insect, for use in the laboratory and small field trials, but not for large scale production. These nematodes can also be cultured *in vitro* on a variety of substrates which can support the growth of their symbiotic bacteria. The symbiotic bacteria can be isolated either from IJs or from the haemolymph of the infected host. The ingredients for nematode culture include a source of nutrients for the symbiotic bacterium and a sterol source for the nematodes.

However, mass production of EPNs has evolved from the first large scale *in vitro* solid-media production, to the *in vivo* production, to the 3-dimensional solid media *in vitro* process (Shapiro Ilan et al., 2012). Production on a commercial scale has been accompanied by using inexpensive protein and sterol source. This method applies to cottage industries or biotechnology companies. Various substances have been used for *in vitro* production such as pork kidney/ peptone agar, pork kidney/beef fat, chicken heart and intestine, clotted cattle blood, wheat, corn fish several fly media and dog food. The EPN has also been produced monoxenically in large liquid fermenters using a combination of plant and animal proteins. This method is highly efficient and quite suitable for companies with significant capital investments because of economies of scale. Yields up to 110,000 IJs / ml in only eight days using medium containing soy flour, corn oil and egg yolk have been reported (Ehlers, 2001). In the scale-up models, liquid monoxenic cultures provide the best economies of scale among all the production methods available. Besides, a broad array of literature on commercial production of EPN is available, which has been reviewed and discussed earlier (Gaugler, 2002; Grewal, 2005).

Formulation and storage

A significant constraint on commercializing EPNs is their poor storage capability. IJs and their mutualistic bacterium must possess a high and stable level of pathogenicity from production to application. Active IJs must be immobilized to prevent depletion of their lipids and glycogen reserves. Immobilization has been accomplished by storing them in the refrigerator (5-15 °C) in oxygenated water where these can be stored up to 5 years. But this is not commercially feasible. Diminishing the activity of nematodes through immobilization and or partial desiccation in or on a substrate increases their viability. Therefore, nematodes formulated in various carriers such as alginate, clay, vermiculite and gel-forming polyacrylamides can be stored for at least six months under refrigeration and at least three months at room temperature. The granular formulation has been developed for soil insects by immobilizing and partially desiccating infective stage, which extended nematode survival and pathogenicity for up to six months at 4 to 25°C, and up to eight weeks at 30°C (Georgis, 1992; Grewal, 1998). Presently, there are about 75 companies mostly in the USA and other parts of the world (UK, Germany, Canada, Italy, Japan, Switzerland, Sweden, Denmark, Australia) which are producing, formulating and marketing the EPN.

Utilization of Entomopathogenic Nematodes in Biological Control of Insects

Compatibility of EPNs with fertilizers and pesticides

Infective juveniles of EPNs are tolerant of short exposures of 2-6 hours to most of the agricultural chemicals including herbicides, fungicides, acaricides and insecticides. EPNs are also compatible with most inorganic fertilizers, but natural populations are negatively affected. However, Heterorhabditids tend to be more sensitive to physical challenges, including pesticides, than Steinernematids. *H. bacteriophora* is quite sensitive to physical stress, but was found to be tolerant to 3 days of laboratory immersion in 58 out of 75 fungicides, herbicides, insecticides and nematicides assayed. Some chemical pesticides (imidacloprid, tefluthrin) and biopesticides (*Paenibacillus popillae* and *Bacillus thuringiensis*) act synergistically with EPN and therefore improve nematode efficacy in inundative applications.

Application Technology

Nematodes can be applied with standard agrochemical equipment including handguns, small pressurized sprayers, mist blowers, electrostatic sprayers, fan sprayers and helicopters. They stand the pressure of 300 Ib /sq. inch and can be delivered with all conventional nozzle type sprayers with openings as small as 50 microns diameter. Other methods of providing nematodes to the target are injection, baits and alginate capsules. Nematodes can also be applied by drip and sprinkler irrigation. This is attractive since it is labour saving, automatically provides sufficient moisture for the nematodes, provide the flexibility of timing of application. Early morning and late evening applications are recommended. Field concentrations exceeding 2.5 billion nematodes/ha are usually applied to ensure that a sufficient nematode population will come in contact with the target insects/stages. Soil temperature at the time of application should range from 18-35°C. Nematodes should be applied to the irrigated field and then should be again watered to maintain sufficient moisture. The application should be made preferably during the evening to avoid UV radiation from the sun and high temperature.

Use of EPNs for managing insect pests

Around the world, different formulations of EPNs are being used for managing various soil and foliar insect pests, which are given in Table 1.

Use of EPNs for managing forest pests

The use of entomopathogenic nematodes (EPNs) in plantation forestry has grown over recent years, with research into the use of nematodes control of species such as the larch sawfly, *Cephalcia lariciphyila*, the spruce budmoth, *Zeiraphera Canadensis* and the pine processionary caterpillar, *Thaumetopoea pityocampa*. The most concerted effort in this area, certainly in Europe, has been regarding the control of the large pine weevil, *Hylobius abietis*. *H. abietis* is a widely distributed pest of plantation forestry occurring throughout Europe and Asia, and is often regarded as the most serious pest in conifer plantation.

Use of symbiont bacteria for managing insect pests

Both *Xenorhabdus* and *Photorhabdus* can be grown independent of their nematode partner under standard laboratory conditions on growth media. They are known to secrete several extracellular products, including lipase, protease and lipopolysaccharides, and many broad-spectrum toxins and antibiotics in the culture medium. Most of the bacterial strains isolated from EPN species are highly toxic when injected, and some of them display lethal oral toxicity as well. Many laboratory and field level experiments have been done to utilise these bacteria as biopesticides independent of their nematode hosts. As early as in 1997 a patent for the use of *Xenorhabdus nematophilus* against fire ants has been issued.

In India, Mohan et al., (2003) demonstrated the direct toxicity of *Photorhabdus* and *Xenorhabdus* to insects under natural conditions. Foliar application of *P. luminescens* resulted in 100 % death of the cabbage white butterfly *Pieris brassicae* larvae infesting the Nasturtium fields within 24 h of application. Foliar application of *P. luminescens* and *X. nematophilus* resulted in 60 % and 40 % mortality to the pupae of *P. xylostella*, respectively. Rajagopal et al., (2006) encapsulated the actively growing cells of *P. luminescens* (2.5×10^7/ bead) in sodium alginate and mixed with sterilized soil and exposed to *Spodoptera litura* larvae. This treatment resulted in 100 % mortality in 48 h, while the use of alginate-encapsulated *H. indica* caused 40 % mortality after 72 h. The LC50 of *Photorhabdus* cells was estimated at 1,010 cells per larva for killing the *S. litura* 6th instar larvae in 48 h.

Table 1. Formulations of EPNs used for management of soil and foliar insect pests

Crop	Insect pest	Nematode species	Formulation
Artichoke	Artichoke plume moth (*Sphenophorus parvulus*)	*Steinernema carpocapsae*	WG, WP,
Berries	Root weevil (*Diaprepes abbreviatus*)	*Heterorhabditis bacteriophora*	Sponge
Citrus	Root weevil (*Diaprepes abbreviatus*)	*S. riobrave*	WG and LC
Craneberry	Root weevil (*Diaprepes abbreviatus*)	*H. bacteriophora*	Sponge
	Craneberry girdler (*Chrysoteuchiatopiaria*)	*S. carpocapsae*	WG, WP
Mushrooms	Sciarid flies (*Lycoriella* spp)	*S. feltiae*	Vermiculite
Ornamentals	Root weevils (*Diaprepes abbreviatus*)	*H. bacteriophora*	Sponge
		H. megidis	WP
	Wood borers (*Holcocercus insularis*)	*S. carpocapsae*	WG,WP
		H. bacteriophora	Sponge
	Fungus gnats (*Bradysia* spp.)	*S. feltiae*	Vermiculite
Turf grass	Scarabs (*Cyclocephala hirta*)	*H. bacteriophora*	Sponge
	Mole crickets (*Scapteriscus vicinus*)	*S. riobrave*	WG
		S. scapterisci	WP
		H. bactriophora	Sponge
	Billbugs (*Sphenophorus venatus*)	*S. carpocapsae*	WG,WP
	Army worm (*Spodoptera frugiperda*)	*S. carpocapsae*	WG,WP
	Cut worm (*Agrotisipsilon*	*S. carpocapsae*	WG,WP
	Web worm (*Cephalcia abietis*)	*S. carpocapsae*	WG,WP

WG = Water dispersible granule; WP = Wettable powder; LC= Liquid concentrate

Indian Scenario

In India, work on EPNs was first initiated by Rao and Manjunath (1966) who demonstrated the use of DD-136 strain of *S. carpocapsae* in the control of insect pests of rice, sugarcane and apple. Search for indigenous strains which are adapted to local conditions was felt extremely necessary. Sivakumar et al., (1989) isolated a strain from Tamil Nadu, which was later described as *H. indica* by Poinar et al., (1992). Since then, much applied work had been done on the exotic strains of EPN species (*S. carpocapsae, S. feltiae, S. glaseri* and *Heterorhabditis bacteriophora*) which has been reviewed by Sankaranarayanan and Askary (2017). The two decades of research on exotic or unidentified strains did not yield very encouraging results, due to the poor adaptability of exotic strains in the local soils. Some other native strains have also been identified as *S. feltiae, S. riobrave, S. bicornutum, S. carpocapsae*, *H. bacteriophora and H. indica* by IARI, New Delhi and NBAIR, Bangalore. Another indigenous heat-tolerant strain isolated from IARI, New Delhi in 2000, was described as *S. thermophilum*, which is the first new species of this genus from India. Field efficacy of the *S. thermophilum* and its biopesticidal formulation Pusa NemaGel was tested against diamond back moth (*Plutella xylostella*), termites (*Odontotemes obesus),* white grubs (*Holotrichia consaguinea*), brinjal shoot borer (*Leucinodes orbonalis*), white fly (*Bemisia tabaci*), tobacco caterpillar (*Spodoptera litura*), gram pod borer (*Helicoverpa armigera)* and mealy bugs (*Phenacoccus solenopsis*), which yielded encouraging results. This species has been licensed to M/S Multiplex Biotech International, Bangalore for its wide-spread use by the farming community and commercialization. Implantation of *Heterorhabditis indica*-infected *Galleria* Cadavers in the soil for biocontrol of white grub infestation in sugarcane fields of Western Uttar Pradesh, India also showed to a feasible method for lepidopteran pest management using EPN (Mohan, 2015; Mohan et al., 2017).

Keeping in view the diverse agro-climatic conditions and a large number of insect pests in this country, there is urgent need to explore, identify and characterize the indigenous entomopathogenic nematode biodiversity, before testing their field efficacy. Almost five decades of EPN research (1966-2020) in India on either exotic or unidentified strains have gone futile as it did not yield very encouraging results in the field trials due to their poor adaptability in local soils. The intensive and extensive basic and applied research on EPNs will definitely enable us to exploit their full biocontrol potential as one of the pest control strategies of integrated pest management schedules. Furthermore, identification of insect toxins and toxic genes in their symbiotic bacteria may prove to be of immense value in developing the biopesticides as well as insect resistant transgenic plants.

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